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QUIET CLEAN SHORT-HAUL EXPERIMENTAL ENGINE (QCSEE)

Under-the-Wing (UTW) Graphite/PMR Cowl Development

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(NASA-CR-135279) QUIET CLEAN SHORT-HAUL EXPERIMENTAL ENGINE (QCSEE) UNDER-THE-WING (UTW) GRAPHITE/PMR COWL DEVELOPMENT (General Electric Co.) 75 p HC A04/MF A01 CSCL 21E
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FOREWORD

The properties of composite materials pertaining to temperature resistance, oxidation resistance, strength, and stiffness have been a pacing factor for composite applications on aircraft jet engines.

Several composite applications in jet engines are rare and nonstructural applications are minimal at this time. Most nonstructural applications are limited to areas of the engine where stress conditions are low and long-time exposure does not exceed 175° C (347° F). Even though polyimide resin systems capable of withstanding long-time exposure at 280° C (536° F) are available, some inherent characteristics of the condensation type resin systems that produce high void content laminates have severely inhibited their use.

The condensation reaction polyimide resin systems in current use yield high void composites which are susceptible to accelerated degradation by oxidation, particularly when there is a pressure gradient or high rate of airflow over the surface of composite parts in an elevated temperature environment. Such conditions are common in jet engines. High void composites are also susceptible to accelerated degradation from high frequency vibrations which are invariably present in jet engines. Low void composites made with the addition reaction type of PI systems, such as PMR-15*, will significantly improve resistance to these adverse conditions.

PMR-15 is an addition reaction polyimide resin system which yields low void composite structures (<2%) with potential long life at 290° C (554° F). The development work in this program consisted of defining the parameters for processing of PMR-15 graphite-reinforced composites by vacuum bag/autoclave techniques and conducting a materials testing program to establish design data.

The information provided by this program will be available for immediate use in fabricating the inner cowl for the NASA Quiet Clean Short-Haul Experimental Engine. This structural application will experience a 290° C (554° F) environment. It will utilize the NASA PMR-15 resin system with Union Carbide T300 woven graphite fabric reinforcement and will establish another milestone in the transition to composites for high temperature structural applications on jet engines.

* The NASA-Lewis developed PMR polyimide resin system with a molecular weight of 1500 is designated as PMR-15.

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SUMMARY

This NASA-funded program was initiated to develop processes for using the NASA-developed PMR-15 addition reaction polyimide resin system to fabricate composite hardware suitable for aircraft jet engine structural applications at 290° C (554° F). Design data were generated to verify that the materials and processes were capable of meeting structural loads and temperature requirements of the application selected to demonstrate the PMR-15 composite.

Work accomplished to meet the intent of the program is delineated in the following summary:

1. Vacuum bag/autoclave processes were developed for making graphite fabric reinforced PMR-15 prepreg into composite laminates.

2. Vacuum bag/autoclave processes were developed for making polyimide honeycomb sandwich panels with PMR-15 composite facings.

3. A supported film polyimide adhesive was developed to bond face sheets to honeycomb core in sandwich panel construction.

4. Simulated hinge and latch joints were fabricated in PMR-15 honeycomb sandwich panels and destructively tested to identify load capabilities of the composite attachment designs.

5. A materials testing program was conducted to establish the static mechanical properties of PMR-15 laminates and honeycomb sandwich panels with PMR-15 face sheets. Testing was conducted at 23° C, 177° C, and 288° C (74° F, 350° F, and 500° F).

6. Creep rupture testing of PMR-15 laminates was conducted at 23° C, 177° C, and 288° C (74° F, 350° F, and 500° F).

7. Low cost tooling concepts were used and verified as being functional for the fabrication of PMR-15 laminate and honeycomb sandwich type construction.

8. A one-half scale model of one inner cowl door (less hardware) for the NASA Quiet Clean Short-Haul Experimental Engine was fabricated to demonstrate that the PMR-15 prepreg could be processed satisfactorily by vacuum bag/autoclave techniques to make complex geometrical shapes in both laminate and honeycomb sandwich types of construction.

INTRODUCTION

The Plastics Applications Development Unit of the General Electric Company, Aircraft Engine Division, Evendale, Ohio, conducted this program to apply the NASA PMR-15 resin system to high temperature structural applications on aircraft jet engines. Previous investigations (References 1 and 2) have shown that PMR-15 has the potential for meeting the structural requirements.

NASA Contract NAS3-18021, defines specific tasks to be performed in meeting the requirements of the development contract. The General Electric Company Plastics Unit translated the tasks defined by NASA into goals on a milestone-type program, to be used as a guide and schedule for conducting the program. Those goals are listed below:

1. Determine the requirements for a woven graphite fabric reinforced PMR-15 prepreg which can be processed by vacuum bag/autoclave techniques.

2. Identify a commercial source for the procurement of woven graphite fabric reinforced PMR-15 prepreg.

3. Develop a process for making laminates and honeycomb sandwich construction with graphite fabric reinforced prepreg using vacuum gas/autoclave techniques.

4. Fabricate and conduct destructive tests on simulated QCSEE inner cowl joints.

5. Conduct a materials testing program to generate design data for graphite fabric reinforced PMR-15 composites.

6. Develop a tooling concept, fabricate the tooling, and manufacture a subscale section of the QCSEE inner cowl.

7. Develop a tooling concept and fabricate tooling to manufacture a full-scale QCSEE inner cowl.

8. Generate General Electric Company Materials Specifications to define requirements and control procurement of materials used to make graphite fabric reinforced PMR-15 composite parts.

Payoff information will consist of processing parameters and design data which can be used for making high temperature resistant structural composite applications on aircraft jet engines. This is a significant improvement in the state of the art for composite applications which will permit weight and cost reductions in future jet engine hardware.

1.0 MATERIALS

Materials which were used in the PMR-15 polyimide cowl development programs are listed in the following tabulation. They are listed in two groups for the purpose of differentiating between materials which were used in composite construction and support materials used in processing the composites. Candidate materials which were used in the preliminary screening program are included in this list. Those materials which were selected for making the inner cowl, through the screening process, are now covered by Military, General Electric Company, or other specifications acceptable to the Government for source control.

COMPOSITE MATERIALS

	Material	Source
1.	PMR-15 Prepreg T300/182/ PMR-15 24 x 24 construction	Fiberite Corporation 501-599 W. Third Street Winona, Minnesota 55987
2.	PMR-15 Prepreg T300/182/ PMR-15 24 x 24 construction	U.S. Polymeric, Inc. 700 E. Dyer Road Santa Ana, California 92707
3.	PMR-15 Prepreg T300/182/ PMR-15 24 x 24 construction with heat cleaned finish	Hexcel Products, Inc. P.O. Box 709 Belair, Maryland
4.	PMR-15 Prepreg T300/182/ PMR-15 24 x 24 construction with heat cleaned finish	Ferro Corporation, Composites Div. 3512-20 Helms Avenue Culver City, California 90230
5.	PMR-15 Prepreg T100/182/ PMR-15 24 x 24 construction with heat cleaned finish Fiberite HMD-182HC/66A	Fiberite Corporation 501-599 W. Third Street Winona, Minnesota 55987
6.	NR150B2G Supported Adhesive Fiberite #9364BQ	Fiberite Corporation 501-599 W. Third Street Winona, Minnesota 55987
7.	NR150B2G Precursor	E.I. DuPont, DeNemours & Company 1007 Market Street Wilmington, Delaware 19898

COMPOSITE MATERIALS (Concluded)

	Material	Source
8.	Scrim Glass Fabric Style 1620	J.P. Stevens Company Slater Road Slater, South Carolina 29683
9.	Cab-O-Sil	Cabot Corp., Oxides Division 125 High Street Boston, Massachusetts 02110
10.	HRH327 Polyimide Honeycomb Core 64 kg/m^3 -(4 lbs/cu-ft) (3/8 inch) (9.52 mm)	Hexcel Structural Products Old Post Road Belair, Maryland 21014
11.	BR34 Adhesive Primer	American Cyanamid Company Bloomingdale Department Havre de Grace, Maryland 21078

PROCESS MATERIALS

1.	Silastic (R) E RTV Rubber	Dow Corning Corporation Midland, Michigan 48640
2.	Sylgard (R) 187 Encapsulating Rubber	Dow Corning Corporation Midland, Michigan 48640
3.	Kapton (R) H-Film	E.I. DuPont, DeNemours & Company 1007 Market Street Wilmington, Delware 19898
4.	RTV Sheet per MIL-R-5847 Class II, Grade 70	Connecticut Hard Rubber Company 407 East Street New Haven, Connecticut 06509
5.	Dapocast (R) #HT56 Castable Silicone RTV	D Aircraft Products Company 1808 National Street Anaheim, California 92801
6.	SMC #650 Calendered B-Staged Elastomeric Sheet Stock	D Aircraft Products Company 1808 National Street Anaheim, California 92801
7.	Tan Release Fabric	Hexcel Products, Inc. Coast Manufacturing Division 11711 Dublin Boulevard Dublin, California 94566

PROCESS MATERIALS (Concluded)

	Material	Source
8.	Celgard (R) #4510 Microporous Polypropylene Film	Celanese Plastics Company Box 828 Greer, South Carolina
9.	Style 7781 Fiberglass Fabric	J.P. Stevens Company Slater Road Slater, South California 29683
10.	DAPCO #2010-1 High Temp. Vacuum Bag Sealer Strip	D Aircraft Products Company 1808 National Street Anaheim, California 92801

The candidate composite materials were subjected to a screening process for the purpose of selecting those materials which were considered most suitable for cowl development, materials testing to develop design data, and for product applications in jet engines.

Although processibility and preliminary results of limited mechanical properties' testing were significant factors in the choice of materials, the selections were not made on that basis alone. Major emphasis was placed on material cost and delivery time. Vendor assurance that the product line would be continually available as long as a need existed was also given particular attention in the selection of suppliers.

Immediately after the materials selections were made, the Ceneral Electric Company initiated materials specifications to govern the manufacture and procurement of vendor supplied materials. Some specific materials, such as Style 1620 fiberglass scrim fabric, have been used in aerospace applications over a period of many years without formal specification coverage. Since materials of this type are produced commercially in great volume and do not perform a structural function, specification coverage has not been considered relevant.

A list of the materials selected for cowl development and evaluation and the specifications pertaining to those materials are given in the following tabulation:

	Material	Specification
1.	PMR-15 Prepreg TH300/182/ PMR-15 24 x 24 construction	General Electric Company Aircraft Engine Group Spec. A50TF187 Preimpregnated Woven Graphite Fabric General Electric Company Aircraft Engine Group Spec. A50TF186 Graphite Fabric

	Material	Source
2.	NR15CB2G Supported Adhesive	General Electric Company Aircraft Engine Group Spec. 4013194-636 Thermoplastic Polyimide Resin Structural Adhesive
3.	Polyimide Honeycomb Core	General Electric Company Aircraft Engine Group Spec. A50TF136 Glass Reinforced Polyimide Honeycomb
4.	BR34 Adhesive Primer	General Electric Company Aircraft Engine Group Spec. A50TF48 Polyimide Adhesive Film and Primer

2.0 COWL PROCESS DEVELOPMENT

The PMR-15 addition reaction polyimide resin system is a recent development in the high temperature resin field by the NASA-Lewis Research Center. This resin system was selected as the best candidate to demonstrate a high temperature structural composite application on aircraft jet engines. NASA and General Electric Company jointly selected the inner cowl for the NASA Quiet Clean Short-Haul Experimental Engine as the demonstration vehicle for the PMR-15 resin system in a composite application. The geometry and construction of this honeycomb sandwich design dictated the use of vacuum bag/autoclave processing. The inner cowl was selected for the demonstration because the honeycomb sandwich construction made an ideal composite application. Further, the 290° C (554° F) engine operating temperature in that location approached the upper limit of the service temperature for PMR-15 resin. In addition, honeycomb sandwich composite construction is particularly adaptable to acoustical treatment for sound attenuation which was an integral feature of the inner cowl design.

Work had been done in making flat panel laminates by hot platen press techniques with this experimental resin system, but process parameters for vacuum bag/autoclave procedures were limited (Reference 3). The need to develop and use fabrication processes by vacuum bag/autoclave techniques for processing the PMR-15 inner cowl was a necessary improvement in the state of the art. There were several obviously difficult technical problems to overcome in the process development to yield a good quality composite and this development work was included as an integral part of the program.

Problems which were resolved in the course of developing processes to fabricate good quality composites for the inner cowl are described in the following paragraphs.

Selection of TH300/182/PMR-15 Prepreg Source

General Electric Company elected to select a manufacturing source for the prepreg by a screening process. The fiber selected was Union Carbide Corporation Thornel 300 graphite in 3000 filament tows. The tows were to be woven into a fabric using Style 182 weave with a tow count of 24 x 24 per inch. The resin impregnation was tentatively designated at levels of 48 and 50 percent by weight for the purpose of initial evaluation. The material in prepreg form was procured from four separate vendors:

1. Fiberite Corporation
   501-599 W. Third Street
   Winona, Minnesota 55987
2. U.S. Polymeric, Inc.
   700 E. Dyer Road
   Santa Ana, California 92707
3. Hexcel Products, Inc.
   P.O. Box 709
   Belair, Maryland
4. Ferro Corporation
   Composites Division
   3512-20 Helms Avenue
   Culver City, California 90230

Each of the materials supplied by the four vendors was fabricated into flat panel laminates using a matched die mold. The laminates were characterized for tensile and compressive strength properties at room temperature. These tests were judged to be the most meaningful tool for use in selecting a material for the inner cowl. Ease of vacuum bag/autoclave processing and test results were primary factors in the material selection.

Fiberite Corporation TH300/182/PMR-15 prepreg, with 48 percent by weight resin content, was selected for the full-scale development program on the basis of exhibiting the best and most repeatable properties.

Identification of Autoclave Cure Cycle Parameters

Initial processing studies were made to provide an autoclave cure cycle which would produce quality laminates. The following cure cycle was selected for flat laminate development and is essentially the cure cycle established in Reference 3.

Vacuum Bag/Autoclave Cure Cycle

1. Install layup in autoclave.

2. Apply 50.6 kPa (15 inch) Hg vacuum.

3. Increase temperature to 250-255° C (480-490° F) using a rise rate of 2-3° C (4-5° F) per minute.

4. Apply 689.5 kPa (100 psig) at 250-255° C (480-490° F).

5. Increase temperature to 315° C (600° F) using rise rate of 2-3° C (4-5° F) per minute.

6. Hold 315° C (600° F) a minimum of one hour.

7. Decrease temperature to 65° C (150° F) or less. Decrease pressure and vacuum and remove cured laminate from autoclave.

8. Postcure laminate 24 hours at 315° C (600° F).

This cure cycle yielded panels of good quality and with good properties. Tensile strength exceeded 483 MPa (70,000 psi) and tensile modulus averaged 82.74 GPa (12×10^6 psi). See Table I for tensile test results.

The cure cycle gave excellent results as shown by a number of flat panels fabricated for the generation of static mechanical properties data.

Tack and drape of the PMR-15 prepreg were low due to the nature of the resin system. Still, the tack and drape were adequate for making parts with

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OF POOR QUALITY

Table I. Tensile Strength and Modulus of PMR-15/T300-182.

Material: PMR15-T300/182 GRAPHITE POLYIMIDE COMPOSITE

Test Specification: ASTM D638-72 **Specimen Type:** IITRI

Tensile Strength (S) = $\frac{P}{bd}$

Modulus of Elasticity (E_t) = $\frac{Py}{bdY}$

S = Tensile Strength $N/M^2 \times 10^7$ (psi)

Y = Strain in cm/cm (in/in)

b = Width in cm (inches)

E_t = Modulus of Elasticity in $N/M^2 \times 10^{10}$ (psi $\times 10^6$)

P = Break Load in Kg (lbs)

D = Thickness in cm (inches)

Specimen No	Test Temp °C	Test Temp °F	b cm	b in	d cm	d in	P Kg	P lb	Py Kg	Py lb	Y cm/cm	Y in/in	S $N/M^2 \times 10^7$	S psi	E_t $N/M^2 \times 10^{10}$	E_t psi $\times 10^6$
1	23	74	1.26	.497	.185	.073	1213	2670	1090	2400	.01786	.00703	50.71	73,550	6.48	9.4
2	23	74	1.28	.505	.185	.073	1081	2380	1090	2400	.01570	.00618	44.51	64,500	7.24	10.5
3	23	74	1.27	.501	.185	.073	1104	2430	1090	2400	.01511	.00595	45.78	56,390	7.58	11.0
4	23	74	1.27	.500	.188	.074	1068	2350	1090	2400	.01638	.00645	43.79	63,510	6.96	10.1
5	23	74	1.27	.501	.185	.073	1099	2420	1090	2400	.01638	.00645	45.59	66,120	7.03	10.2
												Average	46.08	66,814	7.06	10.24
1	177	350	1.27	.502	.180	.071	829	1825	1136	2500	.01918	.00755	35.34	51,260	6.41	9.3
2	177	350	1.28	.502	.180	.071	872	1920	1136	2500	.01956	.00770	37.18	53,930	6.27	9.1
3	177	350	1.27	.500	.180	.071	934	2055	1136	2500	.01925	.00758	39.92	57,890	6.41	9.3
4	177	350	1.22	.481	.183	.072	927	2040	1136	2500	.01913	.00753	40.65	58,960	6.62	9.6
5	177	350	1.25	.493	.178	.070	800	1760	1136	2500	.02172	.00855	35.17	51,010	5.68	8.5
												Average	37.65	54,610	6.31	9.16
1	288	550	1.28	.505	.185	.073	1261	2775	1090	2400	.01346	.00530	51.85	75,200	8.45	12.3
2	288	550	1.28	.503	.185	.073	1263	2780	1090	2400	.01341	.00528	52.23	75,750	8.55	12.4
3	288	550	1.28	.505	.185	.073	1158	2550	1090	2400	.01433	.00564	47.65	69,110	7.93	11.5
4	288	550	1.28	.504	.185	.073	1354	2980	1090	2400	.01382	.00544	55.84	80,980	8.27	12.0
5	288	550	1.29	.507	.185	.073	1317	2900	1090	2400	.01372	.00540	54.04	78,380	8.27	12.0
												Average	52.32	75,884	8.29	12.04

compound contours so long as the stiffness did not approach a boardy condition. Fabrication of a one-half scale model segment of the inner cowl verified the prepreg could be used satisfactorily for compound contours.

Selection of Vacuum Bag and and Sealant Materials

One process improvement resulted from the identification of Dow Corning Corporation RTV "E" as a suitable vacuum bag material used with D Aircraft Products DAPCO #2010-1 high temperature vacuum bag sealant strip for the 315° C (600° F) autoclave cure. Another Dow Corning product, Sylgard 187 Encapsulating Resin was found to be equally as good as RTV "E" and had better tear strength, but high tear strength was not a large asset. RTV "E" was selected over Sylgard 187 due to equivalent utility at lower cost. The combination of these two materials ensured a capability to make vacuum bag/autoclave cure cycles at 316° C (600° F).

SMC #650 calendered B-staged elastomer by D Aircraft Products Company was also evaluated as a vacuum bag material. This material was submitted as suitable for 316° C cures, but failed twice successively. Dapocast HT56, also supplied by D Aircraft Products, exhibited the same problems as SMC #650 and both materials were deleted from the candidate materials list.

KAPTON H-film by DuPont was continued in service as a vacuum bag for flat panel laminates with DAPCO 2010-1 sealer strip. RTV silicone sheet per MIL-R-5847 was a satisfactory vacuum bag material, but expensive and difficult to seal, and was deleted from the materials list.

Development of an Adhesive for Bonding PMR-15 Composites in Honeycomb Sandwich Construction

Honeycomb sandwich construction with composite skins normally utilizes a supported adhesive interface to augment the strength of the bond between the honeycomb and composite. Some epoxy systems have been modified to give good adhesion in this type of construction and are categorized as adhesive prepregs. None of the polyimide laminating resin systems, however, are known to have good adhesive properties and it was surmised that PMR-15 would perform similarly. Cocure bonding the honeycomb to PMR-15 prepreg by utilizing the prepreg resin resulted in an inadequate bond. Most of the flatwise tensile specimens failed upon initiating the load. The result proved that a supported adhesive was needed to make honeycomb sandwich panels.

A literature search revealed that NR150B2G polyimide resin system manufactured by E.I. DuPont was an apt candidate for this application. Heat resistant properties of NR-150 and PMR-15 were noted to be generally equivalent. Manufacturing data showed that application of pressure to the NR150B2G was required in the low temperature portion of the cure because of gel at a lower temperature than the PMR-15 resin system. The recommendation was made

to stage the adhesive so that most of the NMP solvent in the NR150B2G resin would be eliminated prior to a vacuum bag/autoclave cure where NR150B2G and PMR-15 were being cured concurrently.

The first attempt at making the adhesive utilized 120 style fiberglass as the carrier which was hand-impregnated with NR-150B2G resin. The impregnated sheets of 120 fabric were then staged 20 to 30 minutes in an air-circulating oven at 150° C (300° F). In addition, the precured PMR-15 composite skin was brush coated and the honeycomb was roller coated with NR-150B2G resin. Both the skin and the coated honeycomb core were staged identically to the impregnated sheet adhesive. The prepared parts were placed on a caul plate, sequentially, beginning with the PMR-15 skin, the NR150B2G supported film adhesive, and HRH-327 polyimide honeycomb core. The assembled panel was vacuum bagged and autoclave cured using a vacuum of 50.6 kPa (15 in.) Hg and 241.3 kPa (35 psig) pressure using a heat rise of 2-3° C (3-5° F) per minute to 177° C (350° F), which was maintained for one hour to set the adhesive. Postcure was not accomplished at this time, but the panel was conditioned 30 minutes at 315° C (600° F) in an air-circulating oven to comply with the recommended procedure of subjecting the adhesive to a temperature 27° C (50° F) higher than the prescribed temperature of the application. Only one face sheet was bonded on panels in this phase of the development work so that adhesive filleting around honeycomb cells at the bond line interface could be visually inspected.

Inspection of the cured adhesive revealed poor fillets and adhesive runs due to high flow during the cure cycle. Flatwise tensile strength varied from 344.7 to 689.5 kPa (50 to 100 psi) which was a marked improvement over panels with no adhesive interface, but short of the design requirement of 689.5 kPa (100 psi) minimum. Panels made by this procedure also exhibited high warp which was attributed to thermal mismatch between the graphite fiber in the PMR-15 composite and the fiberglass carrier for the NR-150B2G adhesive.

The style 120 fiberglass carrier was changed to an open weave scrim style 1620 fabric, to minimize stresses causing the warpage. Also, 6 pph Cabosil by weight of resin solids was added to the NR150B2G adhesive to prevent runs due to drainage of the adhesive along the cell walls.

These changes were effective; the warpage was eliminated and adhesive fillets were of good quality. Flatwise tensile strength improved to 1.72 to 2.06 MPa (250 to 300 psi) and elevated temperature testing showed no significant degradation at 288° C (550° F). See Table II for flatwise tensile strength data.

Compatibility of the NR150B2G and PMR-15 resin systems in a cocure operation still remained to be proven. Roller coating of the honeycomb core and staging of the roller coated core and the supported film were identical to the operations performed when bonding precured skins to the honeycomb. The orientation of the construction was changed since the precured skin was still located on the mold surface and the cocured skin was laminated on top of the

Table II. Flatwise Tensile Strength of PMR-15/T300-182 Honeycomb Sandwich Construction.

Material: PMR15-T300/182 Graphite Polyimide Composite Sandwich with HRH 327 Honeycomb Core

Specification: ASTM C297-61 Specimen Size: 5.1 cm x 5.1 cm (2 in x 2 in)

Flatwise Tensile Strength (S) = $\frac{P}{bd}$ S = Strength in N/M^2 b = Length in cm

t = Thickness in cm P = Break Load in Kg Test Speed: .0254 cm/min

Test Temperature: 23 °C (74 °F)

Specimen	S		Area		D		Length		Width		Thickness	
No	$N/M^2 x10^5$	psi	cm^2	in^2	Kg	lbs	cm	in	cm	in	cm	in
1	14.76	214	25.8323	4.0040	388.4	855	5.0800	2.000	5.0851	2.002	1.524	.600
2	12.20	177	25.6257	3.9720	320.3	705	5.0495	1.988	5.0749	1.998	1.501	.591
3	14.00	203	25.9487	4.0220	371.6	818	5.1054	2.010	5.0826	2.001	1.529	.602
4	15.31	222	25.8842	4.0120	404.0	889	5.0826	2.001	5.0927	2.005	1.527	.601
5	16.07	233	25.7164	3.9864	422.5	930	5.0826	2.001	5.0597	1.992	1.554	.612
Average	14.47	210										
Test Temperature 177°C (350°F)												
1	18.48	268	25.5493	3.9561	481.6	1060	5.0699	1.995	5.0394	1.984	1.549	.610
2	17.17	249	25.7292	3.9880	452.0	995	5.0749	1.998	5.0699	1.996	1.542	.607
3	18.55	269	25.6513	3.9760	486.0	1070	5.0851	2.002	5.0444	1.986	1.549	.610
4	18.41	267	25.4595	3.9462	479.3	1055	5.0343	1.982	5.0572	1.991	1.547	.609
5	17.03	247	25.5746	3.9640	445.0	980	5.0318	1.981	5.0826	2.001	1.544	.608
Average	17.93	260										
Test Temperature 288°C (550°F)												
1	13.24	192	25.6648	3.9780	347.5	765	5.0572	1.991	5.0749	1.998	1.511	.595
2	14.69	213	25.4457	3.9441	382.5	842	5.0165	1.975	5.0724	1.997	1.527	.601
3	14.96	217	25.5355	3.9580	390.7	860	5.0241	1.978	5.0826	2.001	1.534	.604
4	14.27	207	25.8196	4.0020	376.0	828	5.0851	2.002	5.0775	1.999	1.509	.594
5	14.34	208	25.7419	3.9900	377.0	830	5.0724	1.997	5.0749	1.998	1.529	.602
Average	14.30	207										

Type Failure: 100% Core to Adhesive Interface on Vacuum Bag Side of Sandwich Panel

honeycomb on the vacuum bag side of the panel. After the adhesive-coated honeycomb core and supported film adhesive were subjected to the staging operation of 20 to 30 minutes at 150° C (300° F), uncured PMR-15 prepreg was applied over the NR150B2G film and the panel was vacuum bagged for an autoclave cure cycle. The following cycle was used for curing and bonding the cocured skin to the honeycomb sandwich panel assembly.

1. Apply vacuum of 50.6 kPa (15 in.) Hg and 241.3 kPa (35 psig) pressure.

2. Increase temperature at a rise rate of 2 to 3° C (3 to 5° F) per minute to 275° C (525° F). Hold 275° C (525° F) a minimum of two hours.

3. Cool to 65° C (150° F) or less. Remove from autoclave and demold.

Flatwise tensile data showed the adhesive bond of the cocured skin was comparable to the bond of the precured skin. When complete sandwich panels with one precured and one cocured skin were tested for flatwise tensile strength, failure always occurred at the interface of the honeycomb core and supported film adhesive on the cocured skin side. Since the failure value was only slightly less than had been experienced when bond strength was tested on the precured skin only, the adhesive system and process were evaluated as satisfactory for all PMR-15 honeycomb sandwich construction adhesive applications.

3.0 TOOLING FOR PMR-15 POLYIMIDE INNER COWL

Machined steel molds were originally considered the most practical and perhaps the only feasible approach for molding PMR-15 prepreg systems. There were some undesirable aspects to the use of steel molds for autoclave cures to make large contoured shapes. The prime consideration was in the high cost of machining and the long lead time required for steel tools. Another major drawback to steel was high weight which would cause handling problems and require the use of equipment which would otherwise be unnecessary. A final objection to the use of steel was that it increased problems in controlling heat rise rates and the maintenance of a constant temperature over the entire mold surface. When the negative factors of this tooling approach were fully considered, a decision was made to make a concentrated effort to find another approach to making tools for the PMR-15 cure cycles at 315° C (600° F).

Criteria which were considered in the investigation for an alternate mold material were:

1. Thermal stability at 315° C (600° F).
2. A linear coefficient of thermal expansion close to, or less than, steel.
3. Formability to minimize or eliminate close tolerance machine operations.
4. The ability to maintain contours through multiple heat cycles from room temperature to 315° C (600° F).
5. Minimal degradation after exposure to 315° C (600° F) for as long as 50 hours.
6. Short lead time for procurement.
7. Low cost for the completed tool.
8. Low porosity that would maintain a vacuum suitable for vacuum bag/autoclave process techniques.
9. Lightweight for ease of handling.
10. The ability to heat evenly over the entire mold surface and to follow the autoclave heat rise rate with minimal lag.

Composite Tooling Development

The features that were desired in the mold suggested the solution would be found in a composite material and that the composite must utilize a

polyimide resin system to withstand the 315° C (600° F) temperature exposure. It was also necessary that the composite could be initially cured at 150° C to 175° C (300° F to 350° F) against a plastic faced plaster master model to make this mold-making approach cost effective. Postcure operations were intended to be accomplished in an air-circulating oven with the polyimide composite mold separated from the plaster master model during all heat cycles over 150° C (300° F).

DuPont 3301 controlled flow polyimide resin and Style 181 fiberglass fabric with A1100 finish were selected for the mold material. A one-half scale plaster master model of the inner cowl made from U.S. Gypsum Ultracal tooling plaster with an epoxy face coat was used for the molded surface. The master model is shown in Figure 1. The DuPont 3301 prepreg was laminated against the plaster master with an initial autoclave cure at 150° C (300° F). The laminated mold was later postcured to 315° C (600° F) in an air-circulating oven. The mold was postcured without restriction or supports. After postcure, the mold contour was checked against the master model and contour changes were measured at less than 0.76 mm (0.030 inch). The contour change was within the limits acceptable to Design Engineering and the mold was used to cure a PMR-15 laminate.

Porosity and high voids in the polyimide composite allowed continuous airflow through the composite during the autoclave cure cycle and removed most of the PMR-15 resin from the test part. Several attempts were made to seal the mold so that a satisfactory vacuum could be maintained, but were unsuccessful.

Failure to make a usable high temperature polyimide composite mold required an alternate mold material for processing the PMR-15 successfully. MPTL then considered the possibility that the PMR-15 composite might be satisfactorily cured at a somewhat lower temperature; thereby permitting the use of a fiberglass reinforced high temperature epoxy mold.

A high temperature epoxy mold was estimated to be serviceable to a maximum of 275° C (525° F), so it was decided to attempt reducing the 315° C (600° F) cure for PMR-15 to that degree. The first attempt to cure PMR-15 at 275° C (525° F) in an epoxy mold (shown in Figure 2) was an exact duplication of the 315° C (600° F) cure except for the temperature difference. The laminate made by this process had a good appearance, but interlaminar shear strength was noticeably low and was analyzed to be undercured. The second cure was identical in all respects except that the one-hour hold at 275° C (525° F) was increased to two hours to obtain a more advanced cure. That panel appeared to be satisfactory as determined by visual inspection and was given a 24-hour postcure at 315° C (600° F) to ensure maximization of properties. Tensile testing of specimens taken from that panel was equivalent to panels cured at 315° C (600° F) and confirmed that PMR-15 could be satisfactorily processed at 275° C (525° F).

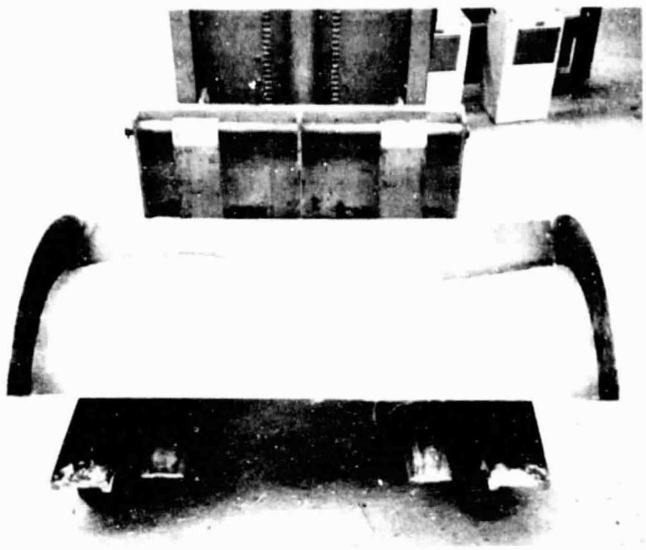

Figure 1. One-Half Scale Plaster Master Model.

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Figure 2. High Temperature Epoxy/Fiberglass Mold and One-Half Scale Inner Cowl Door Segment.

A high temperature fiberglass reinforced epoxy mold was made with Hexcel Corporation's F161 prepreg. This mold was made from the same plaster master that was previously used for making the fiberglass reinforced polyimide mold. After a 175° C (350° F) cure on the plaster master model, the F161 mold was postcured to 275° C (525° F) with no obvious degrading except the mold turned dark, almost black, due to surface oxidation of the resin. A recheck of the contour showed the mold surface to be well within tolerance. Eggcrating structure consisting of half round steel conduit with radial slots to permit forming to the contour was molded into the back surface of the mold to ensure dimensional stability in thermal cycling operations. This mold has performed satisfactorily through more than ten 275° C (525° F) autoclave cure cylces.

The mold for the full-scale inner cowl is being made from the same material using the same basic fabrication approaches. Additional features were included in the full-scale mold, such as removable inserts for forming contour variations required to accept metal hardware and scribed trim lines which transfer to the molded composites during the autoclave cure cycle. The useful life span of this type of tooling cannot be defined due to lack of experience. But, surface repair of the mold with a high temperature epoxy tooling resin could be a feasible means of providing extension to the tool life. Machined metal tooling is not recommended for tooling to make composites utilizing the graphite/PMR-15 resin system with autoclave processes except for very simple shapes requiring large numbers of identical parts. Larger numbers of parts would be required to amortize the higher cost of metal tooling on a reasonable per unit basis.

4.0 SUBSCALE INNER COWL FABRICATION

Fabrication of a one-half scale segment of the inner cowl, without metal hardware, was planned to verify the capability of materials, processes, and tooling for making the inner cowl construction to meet design requirements.

Some facets of the design were considered potential problem areas. The fabrication exercise, therefore, was intended to identify which of the potential problems were actual problems and to determine the magnitude of those problems. In addition to problem identification, construction of the scale model part was expected to be useful in analyses to provide problem solutions. Also, whether or not any problems were encountered, the experience would be helpful in the determination of methods and procedures to be used in fabrication and assembly of the full-scale part.

Special Attention Items in Inner Cowl Fabrication

Items which required special attention in the course of making the inner cowl subscale model are listed below:

1. Feasibility of forming the PMR-15 prepreg to the compound contour of the inner cowl.
2. Conformance of the outer skin to the mold contour after the autoclave cure cycle.
3. Forming the polyimide honeycomb core to the inner surface of outer skin.
4. Bonding the honeycomb core to the inner surface of the premolded outer skin.
5. Splicing and stabilizing the honeycomb core with American Cyanamid BR34 past adhesive and carbon microspheres mixtures.
6. Forming, laminating, and cocure bonding the inner skin to the honeycomb core.
7. Forming composite edge closeouts.
8. Contour conformance of the completed honeycomb sandwich construction.
9. Presence of disbond conditions in the completed honeycomb sandwich as indicated by manual C-scan inspection.
10. Feasibility of repair to disbonded areas.

11. Evidence of degradation or change in contour in the fiberglass reinforced epoxy mold after multiple heat cure cycles.

Feasibility of Forming PMR-15 Composite Skins to Compound Contours

The inner cowl geometry is basically a surface of revolution with a continually changing axial diameter. The surface contour has a complete double reverse over the entire axial length of the part because of increasing and decreasing diameter dimensions and can best be described as similar to an hourglass shape. This type of configuration presents a unique layup problem in that the fabric must be stretched to cover a larger area where the diameter is large and compressed in areas to fit the surface where the diameters are smaller. The prepreg must fit smoothly and without wrinkles over the entire mold surface to preserve structural integrity in the cured composite. Crippled fibers resulting from bends on tight radii in wrinkles and other types of mismatch between the mold and composite prepreg cause a degradation in mechanical properties that will render cured composites inadequate for structural applications. Good drapeability is necessary to cover a surface that is expanding and diminishing in comparison with the original area of the fabric.

Drape in the PMR-15 prepreg was controlled mainly by the solvent level since little or no change in drape could be effected by varying the resin content. The most satisfactory solvent level was found to be eight to ten percent ethanol. That amount of solvent provided the minimum satisfactory drape and was low enough to prevent excess flow of the resin system during the cure cycle.

Dry prepreg was very difficult to form to the inner cowl shape and, after forming, was still more difficult to hold in position. Heat guns were used as an auxiliary aid in forming stiff and boardy prepreg, but the prepreg had a strong tendency to revert to flat sheet form as quickly as it cooled. Reasonable success in forming the boardy material was attained by application of heat while the prepreg was restrained under a vacuum bag. That procedure required removal and reapplication of the vacuum bag one or more times for each ply of material in the laminate due to the tendency to fold and wrinkle during the forming process. Even though a contoured laminate could be formed in that manner, the process was tedious and costly. Evaluation of the problems in forming contoured shapes indicated that the only practical way to facilitate the forming operation was to control drape characteristics by the solvent level in the prepregging operation. The outer skin was satisfactorily formed with the vacuum bag/heat gun process and cured with the autoclave cycle shown on page 6 except that the cure temperature was reduced from 315° C (600° F) to 275° C (525° F) and the time at temperature was increased from one to two hours. Modification of the cure cycle resulted from the tooling development work explained on page 13. Prepreg formed in this manner had a satisfactory work time of three days at room temperature.

Conformance of PMR-15 Composite Skins to Mold Contours After Autoclave Cure Cycles

Autoclave cure cycles were expected to cause contour changes as a result of resin shrinkage in the PMR-15 laminates which would be apparent after removing the vacuum bag. Shrinkage in resin systems as a result of heat cures usually builds stresses into cured laminates which are evidenced by deformation and warpage when the vacuum bag restriction is removed. Configurations with cylindrical segment cross sections normally curl inward circumferentially, causing molded parts to have smaller diameters than the mold.

Resin shrinkage did not cause a contour change in PMR-15 laminates cured on molds fabricated from fiberglass reinforced epoxy prepreg. Molded PMR-15 parts checked against the mold surface after being postcured at 315° C (600° F) showed conformance to the original contour within normal manufacturing tolerances (± min. 0.030 inch).

Excellent adherence to contour and the absence of internal stress loads normally expected, was attributed to the gel temperature of the PMR-15 resin system and the good balance of thermal expansion between the PMR-15 composite and the fiberglass reinforced epoxy mold.

Forming Polyimide Honeycomb to the PMR-15 Composite Outer Skin

Forming HRH-327 glass reinforced polyimide honeycomb core to the inner surface of the outer cowl skin was resolved by using a heat formable honeycomb. The heat formable grade of HRH-327 is identical to the standard honeycomb except that the cure temperature had been limited to 315° C (600° F) rather than a 371° C (700° F) cure for the standard honeycomb. The honeycomb was subjected to 343° C (650° F) for three to five minutes in an air-circulating oven to stabilize the heat in the honeycomb. The honeycomb was then placed in the mold and immediately loaded with sandbags to conform to the mold contour before cooling.

Forming the undercured polyimide honeycomb proved to be comparatively easy, but considerable springback was noted when the weight was removed after cooling. The springback did not prove to be a deterrent to processing since the core could be brought back to the mold contour with minimal force either by dead weight loading or with a vacuum bag used for honeycomb core bonding operations. When the full-scale inner cowl is fabricated, it is intended to overform the honeycomb core so that the configuration will closely match the mold after the springback has occurred. Overforming was not considered necessary for the subscale part because the reduced size minimized handling and fitting problems.

Bonding Honeycomb to the Premolded Outer Skin

HRH-327 glass reinforced polyimide honeycomb core was bonded to the inner surface of the outer skin with NR150B2G adhesive paste and supported

adhesive film using the material and procedures described in the process development phase of the program.

After forming the honeycomb, the bonding surface of the PMR-15 premolded outer skin was cleaned with MEK solvent and air-dried for 20 minutes. The NR150B2G adhesive solution was then brush coated onto the skin and roller coated onto the bonding surface of the honeycomb core followed by a precure of 15 to 20 minutes at 150° C (300° F) in an air-circulating oven. Supported NR150B2G adhesive in sheet form was precured in the same cycle. After cooling, the supported adhesive was fitted to the PMR-15 skin and the honeycomb core was fitted into position over the skin. The assembly was then bagged with nylon film and cured one hour at 175° C (350° F) in an air-circulating oven under a minimum of 88.0 kPa (26 in.) Hg vacuum. The bond assembly was then cooled and debagged and prepared for application of the outer skin (Figure 2). This procedure provided the best bonds between PMR-15 composites and honeycomb core and maintained stable bond strength from room temperature to 288° C (550° F).

Splicing and Stabilizing Honeycomb Core with BR34 Paste Adhesive and Carbon Microspheres

American Cyanamid Company's BR34 adhesive primer, with 12 to 13 parts by weight of carbon microspheres, was used as an edge stabilizer and core splice material for HRH-327 glass reinforced polyimide honeycomb core in the scale model inner cowl. BR34 adhesive primer with carbon microspheres was already an approved material for 288° C (550° F) rub seal applications in GE engines. The mixture was known to be lightweight, 865 kg/m^3 (54 pcf), and to have good adhesion properties over the approved temperature range, -54 to 288° C (-65 to 550° F). When used as a splice material in the inner cowl, the mixture was applied to the full depth of the honeycomb cells and extended one to one and one-half cells on both sides of the splice line. With the 1.9 to 25.4 mm (3/8 inch) cell size, the core splice was 3/4 to one-inch wide. Edge stabilization was necessary to prevent core damage and deformation in the autoclave cure cycles and extended two to three cells inward from all unsupported edges of the honeycomb core.

The core stabilization and edge fill operation was accomplished after the honeycomb core was bonded to the inner skin. This was not combined with any other laminating or bonding operation due to the cure cycle and finishing operations required to maintain the surface of the filler flush with the surface of the honeycomb. The cure cycle is as follows:

1. Use nylon film for vacuum bag.

2. Place assembly in circulating air oven; apply 88.0 to 98.0 kPa (26 to 29 in.) Hg vacuum.

3. Increase heat to 190° C (350° F) at 1-2° C (2-3° F) per minute.

4. Maintain temperature at 190° C (350° F) for a minimum of one hour.

5. Cool tc 120° C (150° F) or less. Remove assembly from oven and remove vacuum bag.

The irregular surface was reworked to the surface contour of the honeycomb core by hand benching.

The materials and processes used for core stabilization and splicing were completely successful and will be used in fabricating the full-size inner cowl.

Forming, Laminating, and Cocure Bonding the Inner Skin to Honeycomb Core

Forming the inner skin to the compound contour was further complicated by the addition of honeycomb core which varied in height from 9.2 to 25.4 mm (0.375 to 1.0 inch) in thickness (one-half the dimensions of the full-scale inner cowl) to no honeycomb in one 10.2 cm (4 inch) long circumferential area near the midsection of the cowl. Circumferential transitions in thickness were tapered 30 to 45° except for a right-angle transition at the leading edge. Axial transitions were on theoretical radius lines, near 90°, for mating to adjacent parts. Axial transitions were characterized by abrupt contour changes required for the installation of hinges, latches, and a seal extending the full length of both doors where they mated between the latches. The problems in making the subscale inner cowl were somewhat minimized by omitting the seals and metal hardware.

There was need for a pregpeg with maximum drape to match such an irregular contour. The PMR-15 prepreg used to make the subscale cowl was actually in a boardy condition and, without auxiliary heat, could not be fitted to the honeycomb surface without crippling the graphite fibers in the prepreg during the forming process. Later experience showed that ethanol solvent maintained at a level of 8 to 10 percent eliminated that problem.

An acceptable fit between the skin and honeycomb core was achieved by fitting and tailoring each ply of prepreg to the honeycomb core and composite closeout shapes. The prepreg was not shaped to sharp bends and transition areas at this time, but was left comparatively loose fitting to avoid damage to the graphite fibers. A transparent nylon film bag was then fitted over the part and edge sealed beyond the periphery of the part. A vacuum of 3.3 to 10.1 cm (1 to 3 inches) Hg was applied to load the prepreg lightly and a heat gun was used to soften the material as it was moved into position. The low vacuum permitted the prepreg sheet to be moved externally by hand to smooth out wrinkles and maintain good butt joints between the tailored patterns. When the best fit was attained, the vacuum was increased and additional heat applied to tight bends and sharp transition areas. Full vacuum was applied when the prepreg was finally fitted completely and maintained a minimum of 15 minutes prior to removing the vacuum bag to begin fitting the next ply of laminate.

This procedure formed a semipermanent set in the prepreg shape and tack between plies. There was considerable springback when the vacuum load was released from the first ply of material, but springback was minimal after all three plies were laminated in place. The preformed skin was temporarily removed from the honeycomb for the application of adhesive to the bonding surfaces of the honeycomb core and precured PMR-15 outer skin.

The honeycomb core was next roller coated with NR150B2G filled paste adhesive and the faying surfaces of the preformed inner skin were given a light adhesive brush coat. NR150B2G supported film adhesive in sheet form was also cut roughly to the size and shape of the entire bonding surface. The adhesive coated preformed part and the supported film were placed in an air-circulating oven and dried 20 to 30 minutes at 150° C (300° F). After cooling to room temperature, the film was applied to the bonding surfaces with the use of a heat gun for forming and tailoring butt joints in place. The preformed inner skin was then repositioned over the precured outer skin and honeycomb in preparation for the autoclave cure cycle to make the honeycomb sandwich assembly. The following cure cycle was used for the cocured skin laminating and bonding operation.

1. Vacuum bag part in four mils KAPTON H-film for 274° C (525° F) cure.

2. Leave part under full vacuum at room temperature for a minimum of eight hours.

3. Install part in autoclave and apply vacuum of 50.6 kPa (15 inches Hg) and a positive pressure of 24.3 kPa (35 psig).

4. Begin heat rise of 2-3° C (3-5° F) per minute.

5. Bring part to 274° C (525° F) and hold for a minimum of two hours under vacuum and pressure.

6. Reduce temperature to 65° C (150° F) or less under vacuum and pressure.

7. Remove from autoclave and debag.

8. Accomplish clean-up work as required to prepare for next operation.

9. Postcure 24 hours at 315° C (615° F).

Forming Composite Edge Closeouts

The subscale model provided natural closeouts on three sides, but the leading edge was made with no closeout at the ring location. A three-ply channel of PMR-15 composite prepreg was specified to capture the inner and outer skins and the exposed honeycomb at that location.

The original intent was to mold a channel formed in a cylindrical segment and seconarily bond it around the leading edge. After the honeycomb sandwich assembly was completed, it seemed a better fit could be made by

laminating the closeout directly onto the inner cowl segment. Consequently, the three-ply channel was tailored and preformed to fit the leading edge of the part using the vacuum bag/heat gun method of preforming one ply at a time. Each ply was staggered about 6.25 mm (1/4 inch) so that the joint to the inner cowl skins would be tapered rather than stepped. When the preform was completed, it was removed from the part to prepare an adhesive interface. The bonding surfaces of the cowl segment were painted with NR150B2G liquid adhesive and staged 20 to 30 minutes at 150° C (300° F). The part was cooled to room temperature and the preformed channel was repositioned on the leading edge of the part. The entire cowl segment was then encapsulated in an envelope type vacuum bag and autoclave cured identically to the cocured inner skin.

Contour Conformance of the Completed Honeycomb Sandwich Construction

After the inner cocured skin was cured to complete the honeycomb sandwich construction, it was fitted back into the mold to check for variance in contour. The contour was maintained within 0.76 mm (0.030 inch). Since 0.76 mm (0.030 inch) was less than the design requirement, the process and tooling construction were judged satisfactory for making the full-scale inner cowl (Figures 3 and 4).

Manual C-Scan Inspection for Disbond Conditions in the Completed Honeycomb Sandwich Construction

The completed inner cowl segment was nondestructively tested for disbond areas by a manual C-Scan. The inspection was successful in identification of a disbond area about 76 x 127 mm (3 x 5 inches) located near the forward end of the inner skin. The inner skin was removed one ply at a time until the honeycomb core was exposed in the disbonded area. Each ply was stepped back 9.6 to 12.7 mm (3/8 to 1/2 inch) around the outer periphery so that the repair would have an overlap on each skin ply to provide additional bond area and to make a tapered repair area. Removal of the skin in the disbonded area allowed a positive check on the C-Scan operation and it was found that the overall area and the periphery of the disbond were accurately defined (Figures 5, 6 and 7).

Feasibility of Repair - Disbonded Areas

Since the composite edge closeout had already been made successfully with an adhesive interface at the precured honeycomb sandwich, and a cocured honeycomb skin applied simultaneously, this procedure was also used to repair the disbonded area. The inner cowl segment was used as the tool and encapsulated in a KAPTON film envelope-type vacuum bag. The 274° C (525° F) autoclave cure was identical to that used for the original cocured skin. After curing, the repair was finished by hand benching. A C-Scan inspection showed the repair was succesful.

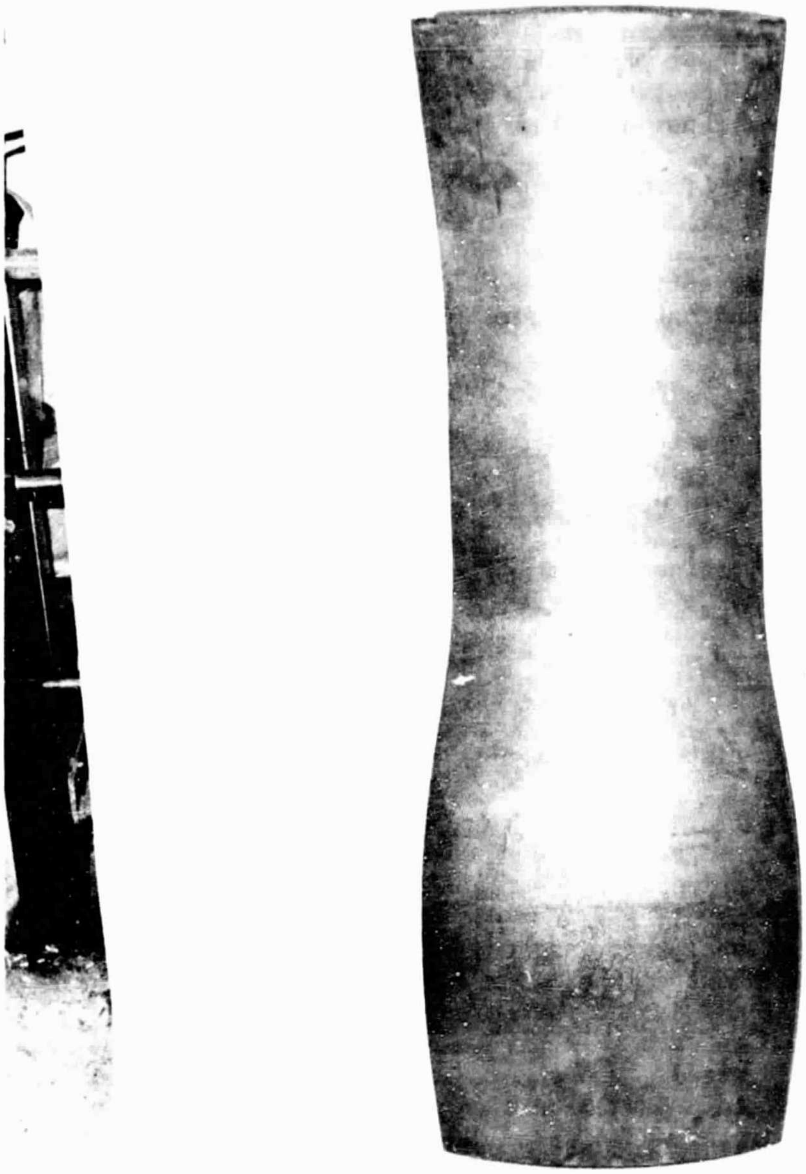

Figure 3. One-Half of Scale Model Inner Cowl Door - Outer Skin View.

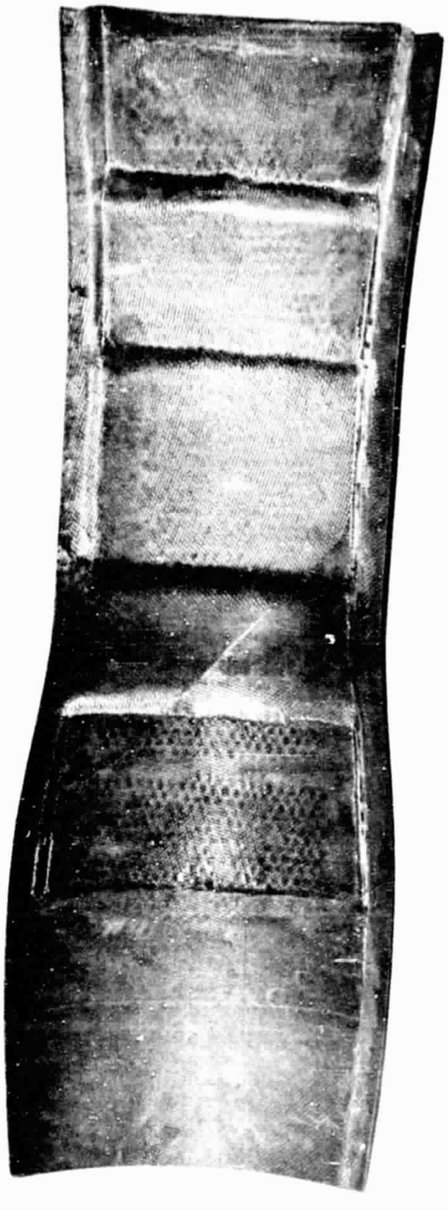

Figure 4. One-Half of Scale Model Inner Cowl Door - Inner Skin View.

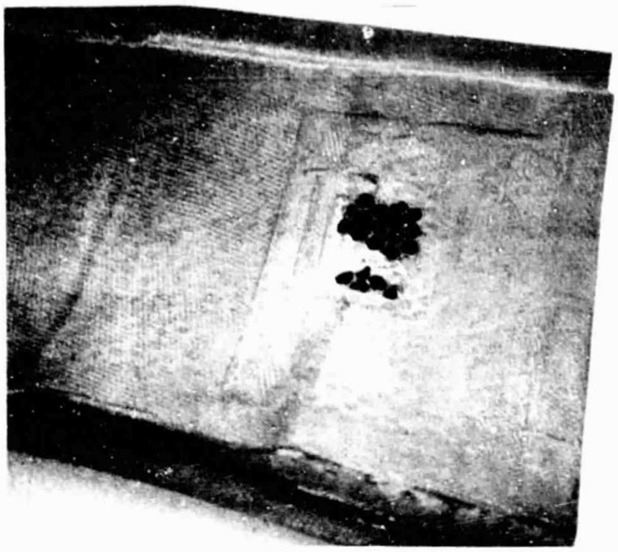

Figure 5. Inner Skin Removed at Disbonded Area on Honeycomb Core.

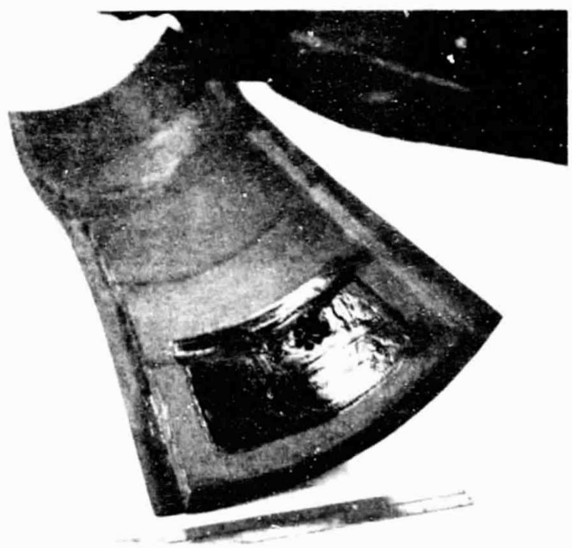

Figure 6. NR150B2G Adhesive Applied on Honeycomb Core.

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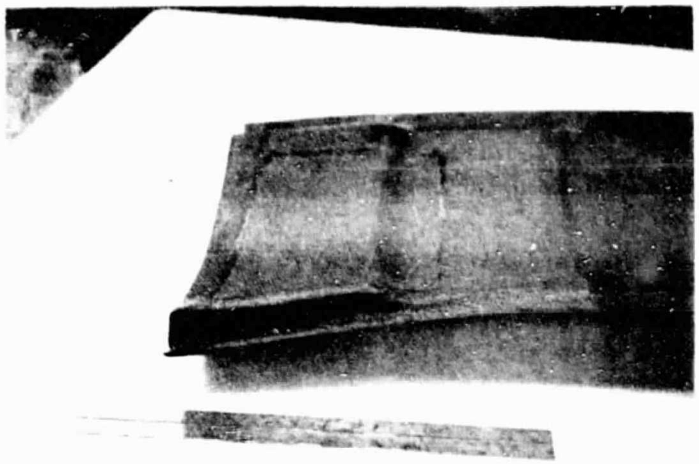

Figure 7. Completed Repair of Disbonded
Inner Skin.

Inspection for Degradation or Contour Change of the Fiberglass Reinforced Epoxy Mold

An inspection to determine the condition of the mold was conducted after completing the final 274° C (525° F) cure of the subscale inner cowl. There was no significant degradation in the epoxy laminate material; the mold fit the contour of the plaster master model as closely as it did on the original inspection. There is inadequate information to determine the useful life of F161 epoxy prepreg as a mold for autoclave cure cycles at 274° C (525° F), but because of the general condition of the tool it is estimated that the mold could be used for several additional cycles. This low cost cooling concept will be used to make the full-scale inner cowl and is considered the best concept for short-run production of parts with compound contours when 274° C (525° F) autoclave cures are required.

5.0 TEST SPECIMEN PREPARATION AND TEST METHODS

A broad scope of mechanical and physical properties' testing was included in the inner cowl materials evaluation. The majority of testing was conducted in accordance with ASTM and other standard test specifications accepted by the aerospace industry. In addition to the standard tests, a number of special tests were conducted on specimens specially constructed to evaluate specific details of the inner cowl design.

Standard test specimens were manufactured to generate materials data for PMR-15 composite material by using the materials and processes described in this report. Specimens were tested in the "as-molded" condition and with laser-drilled holes. The inner skin of the cowl was proposed with laser-drilled holes which were used with the honeycomb sandwich construction to provide acoustic attentuation during engine operation. Laser-drilled skin specimens were tested to characterize tensile and compressive strengths and to determine the load-carrying capability of the inner skin after the removal of composite material by the laser hole drilling operation. The laser hole pattern established by acoustical engineering consisted of 49 holes 0.159 cm (0.625 inch) diameter per 6.45 sq cm (1 sq inch) located in a rectangular pattern with equally spaced hole centers. A description of the test specimens is given in the heading of each table, including identification of laser drilled specimens. The heading for each table also provides titles of test specifications and methods, test temperatures, and the number of specimens tested under each condition.

Nonstandard test specimens and test methods used to make a structural evaluation of specific portions of the design construction are covered in greater detail. These items are described by drawings, sketches, and supplemental information to the extent necessary to explain the specimen construction, test methods, and reasons for conducting the tests. Special tests were conducted to make a structural evaluation of such items as hinge and latch installations. Test results are presented in Tables III through XIX.

Standard Tests

Flat panel laminates and honeycomb sandwich panels used to make test specimens were manufactured using the materials and processes which will be used to manufacture the full-scale inner cowl. The processes are described in Section 4.0 of this report.

The PMR-15 graphite fabric prepreg was laminated with all plies parallel in the warp direction unless specifically noted otherwise. The number of plies in flat panels was varied as necessary to attain the required thickness for each type of test specimen. Also, to the extent that it was practical, panels were sized so that all identical test specimens could be taken from a single panel.

Table III. Tensile Strength and Modulus of PMR-15/T300-182 with Laser Drilled Holes.

Material: PMR15/T300-182 Graphite Polyimide Composite

Test Specification: ASTM D638-72 Specimen Type: IITRI

Tensile Strength (S) = $\frac{P}{bd}$

Modulus of Elasticity (E_t) = $\frac{Py}{bdY}$

S = Tensile Strength $N/M^2 \times 10^7$ (psi)

Y = Strain in cm/cm (in/in)

b = Width in cm (inches)

E_t = Modulus of Elasticity in $N/M^2 \times 10^{10}$ (psi $\times 10^6$)

P = Break Load in Kg (lbs)

D = Thickness in cm (inches)

Special Condition: 1/16 inch laser drilled holes

Specimen No	Test Temp °C	Test Temp °F	b cm	b in	d cm	d in	P Kg	P lb	Py Kg	Py lb	Y cm/cm	Y in/in	S $N/M^2 \times 10^7$	S psi	E_t $N/M^2 \times 10^{10}$	E_t psi$\times 10^6$
1	23	74	2.093	.824	.1194	.047	192	422	545	1200	.02261	.00890	13.03	18,900	2.41	3.5
2	23	74	2.093	.824	.1194	.047	250	550	545	1200	.02540	.01000	9.80	14,210	2.14	3.1
3	23	74	2.093	.824	.1168	.046	252	553	545	1200	.02210	.00870	10.08	14,620	2.48	3.6
4	23	74	2.093	.824	.1168	.046	267	588	545	1200	.02413	.00950	10.69	15,510	2.28	3.3
5	23	74	2.096	.825	.1194	.047	253	556	545	1200	.02413	.00950	9.88	14,330	2.28	3.3
											Average		10.70	15,514	2.31	3.36
1	177	350	2.093	.824	.1143	.045	207	245	545	1200	.02794	.01100	8.47	12,280	2.00	2.9
2	177	350	2.098	.826	.1194	.047	253	556	545	1200	.02388	.00940	9.88	14,330	2.26	3.3
3	177	350	2.098	.826	.1219	.048	239	526	545	1200	.02159	.00850	9.16	13,280	2.48	3.5
4	177	350	2.098	.826	.1169	.046	229	504	545	1200	.02134	.00840	9.14	13,260	2.62	3.8
5	177	350	2.098	.826	.1169	.046	262	576	545	1200	.01981	.00780	10.45	15,160	2.76	4.0
											Average		9.42	13,664	2.43	3.52
1	260	500	2.098	.826	.1168	.046	243	534	545	1200	.01905	.00750	9.69	14,050	2.90	4.2
2	260	500	2.100	.827	.1194	.047	254	560	545	1200	.02184	.00860	9.93	14,400	2.48	3.6
3	260	500	2.103	.828	.1168	.046	253	558	545	1200	.02159	.00850	10.10	14,650	2.55	3.7
4	260	500	2.100	.827	.1194	.047	250	550	545	1200	.01905	.00750	9.75	14,140	2.83	4.1
5	260	500	2.100	.827	.1169	.046	218	480	545	1200	.02565	.01010	8.71	12,630	2.14	3.1
											Average		9.60	13,920	2.58	3.74

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Table IV. Compressive Strength and Modulus of PMR-15/T300-182.

Material: PMR15-T300/182 Graphite Polyimide Composite

Test Specification: ASTM D695-69 Type Specimen: Dogbone Test Speed: .127 cm/min (.05 in/min)

Compressive Strength (S) = $\frac{P}{bd}$ E_c Modulus of Elasticity (Y) = Strain M/M (in/in)

P = Break Load in Kg b = Width in cm d = Thickness in cm

Test Temperature: 23 °C (74 °F)

Specimen No	S $MN^2 \times 10^7$	S psi	d cm	d in	b cm	b in	Area cm^2	Area in^2	P Kg	P lbs	Py Kg	Py lbs	Y cm/cm	Y in/in	E_c $MN^2 \times 10^{10}$	E_c psi x 10^6
1	51.53	74,770	.277	.109	1.275	.502	.3532	.0547	1817	4,000	2.73	6.00	.02590	.01020	7.45	10.8
2	49.83	72,270	.274	.108	1.273	.501	.3488	.0541	1776	3,910	2.73	6.00	.03027	.01192	6.41	9.3
3	49.54	71,850	.274	.108	1.270	.500	.3480	.0540	1763	3,880	2.73	6.00	.02971	.01170	6.96	9.5
4	51.52	74,720	.274	.108	1.275	.502	.3494	.0542	1840	4,050	*	*	*	*	*	*
5	48.46	70,280	.277	.109	1.270	.500	.3518	.0545	1740	3,830	2.28	5.00	.02438	.00960	6.62	9.6
Average	50.18	72,760												Average	6.77	9.8

* Compressometer Malfunction

Test Temperature 177°C (350°F)

Specimen No	S $MN^2 \times 10^7$	S psi	d cm	d in	b cm	b in	Area cm^2	Area in^2	P Kg	P lbs	Py Kg	Py lbs	Y cm/cm	Y in/in	E_c $MN^2 \times 10^{10}$	E_c psi x 10^6
1	35.55	51,560	.277	.109	1.270	.500	.3518	.0545	1277	2,810	2.73	6.00	.02438	.01106	6.90	10.0
2	41.37	60,000	.274	.108	1.270	.500	.3480	.0540	1472	3,240	2.73	6.00	.03439	.01354	5.65	8.2
3	35.73	51,850	.274	.108	1.270	.500	.3480	.0540	1272	2,800	2.73	6.00	.02717	.01070	7.17	10.4
4	40.09	58,150	.274	.108	1.270	.500	.3480	.0540	1427	3,140	2.50	5.50	.02717	.01170	6.00	8.7
5	35.96	52,010	.277	.109	1.273	.501	.3526	.0546	1290	2,840	1.82	4.00	.02250	.00886	5.72	8.3
Average	37.72	54,715												Average	6.3	9.1

Test Temperature 260°C (500°F)

Specimen No	S $MN^2 \times 10^7$	S psi	d cm	d in	b cm	b in	Area cm^2	Area in^2	P Kg	P lbs	Py Kg	Py lbs	Y cm/cm	Y in/in	E_c $MN^2 \times 10^{10}$	E_c psi x 10^6
1	37.79	54,810	.274	.108	1.270	.500	.3480	.0540	1345	2,960	2.73	6.00	.03535	.01392	5.52	8.0
2	31.28	45,370	.274	.108	1.270	.500	.3480	.0540	1113	2,450	2.73	6.00	.03576	.01408	5.45	7.9
3	27.20	39,450	.277	.109	1.270	.500	.3518	.0545	977	2,150	2.73	6.00	.03322	.01308	5.79	8.4
4	25.28	36,670	.274	.108	1.270	.500	.3480	.0540	890	1,960	2.73	6.00	.03606	.01420	5.28	7.8
5	28.80	41,770	.274	.108	1.273	.501	.3488	.0541	1027	2,260	2.73	6.00	.03606	.01420	5.38	7.8
Average	30.07	43,615												Average	5.30	8.0

Table V. Compressive Strength and Modulus of PMR-15/T300-182 with Laser Drilled Holes.

Material: PMR15-T300/182 Graphite Polyimide Composite

Test Specification: ASTM D695-69 Type Specimen: Dogbone Test Speed: .127 cm/min (.05 in/min)

Compressive Strength (S) = $\frac{P}{bd}$ E_c Modulus of Elasticity (Y) = Strain N/M (in/in)

P = Break Load in Kg b = width in cm d = thickness in cm

Special Test Condition: .064 diameter laser drilled holes

Specimen No.	S $N/M^2 \times 10^7$	S psi	d cm	d in	b cm	b in	Area cm^2	Area in^2	P Kg	P lbs	Py Kg	Py lbs	Y cm/cm	Y in/in	E_c $N/M^2 \times 10^{10}$	E_c psi x 10^6
Test Temperature 23°C (74°F)																
1	4.737	6,870	.295	.116	1.275	.502	.3761	.0582	182	400	273	600	.00875	.00384	1.926	2.7
2	5.523	8,010	.290	.114	1.268	.499	.3677	.0569	207	456	273	600	.00640	.00252	2.906	4.2
3	4.978	7,220	.290	.114	1.275	.502	.3698	.0572	188	413	273	600	.01372	.00540	1.310	1.9
4	4.709	6,830	.292	.115	1.278	.503	.3732	.0578	179	395	273	600	.01046	.00412	1.721	2.5
5	3.758	5,450	.292	.115	1.278	.503	.3732	.0578	143	315	273	600	.00691	.00272	2.620	3.8
Average	4.741	6,875											Average		2.594	3.02
Test Temperature 177°C (350°F)																
1	2.958	4,290	.292	.115	1.278	.503	.3732	.0578	113	248	273	600	.00620	.00244	2.985	4.3
2	4.192	6,080	.292	.115	1.273	.501	.3717	.0576	159	350	273	600	.01280	.00501	1.448	2.1
3	3.613	5,240	.284	.112	1.273	.501	.3615	.0561	134	294	273	600	.01728	.00678	1.103	1.6
4	2.565	3,720	.295	.116	1.278	.503	.3770	.0583	99	217	273	600	.01336	.00526	1.379	2.0
5	2.517	3,650	.295	.116	1.273	.501	.3756	.0581	96	212	273	600		.00710	1.034	1.5
Average	3.169	4,595											Average		1.586	2.3
Test Temperature 260°C (500°F)																
1	2.427	3,520	.292	.115	1.275	.502	.3723	.0577	92	203	273	600	.01803	.00588	1.241	1.5
2	2.482	3,600	.297	.117	1.278	.503	.3796	.0589	96	212	273	600	.01417	.00558	1.241	1.8
3	3.985	5,780	.295	.116	1.280	.504	.3776	.0585	154	338	273	600	.01372	.00540	1.310	1.9
4	4.482	6,500	.292	.115	1.263	.497	.3688	.0572	170	372	273	600	.01483	.00584	1.241	1.8
5	3.358	4,870	.295	.116	1.278	.503	.3770	.0583	129	284	273	600	.01331	.00524	1.379	2.0
Average	3.3168	4,855											Average		1.282	1.9

Table VI. Climbing Drum Peel Strength of PMR-15/T300-182 Honeycomb Sandwich Construction.

Material: PMR15-T300/182 Graphite Polyimide Composite Sandwich with HRH 327 Honeycomb Core

Specification: ASTM D1781-62

$$\text{Climbing Drum Peel (T)} = \frac{(ro-ri)\,(fp-fo)}{W}$$

ro = 6.3530 cm (2.5015 in)

fp = lbs   T = NM/Meter Width   W = inches

Specimen No	W cm	W in	fp (kg) Max	fp (kg) Min	fp (kg) Avg	fp (lbs) Max	fp (lbs) Min	fp (lbs) Avg	T NM/M	T in lb/in width	ri cm	ri in	ro cm	ro in
Test Temperature 23°C (74°F)														
1	7.638	3.007	70.4	50.0	64.0	155	110	141	68.94	15.5	5.1333	2.0210	6.3538	2.5015
2	7.653	3.013	72.0	50.0	65.0	158	110	143	57.38	12.9	5.1358	2.0220	6.3538	2.5015
3	7.643	3.009	72.0	41.0	62.0	147	91	136	57.38	12.9	5.1346	2.0215	6.3530	2.5015
4	7.569	2.980	-	-	-	-	-	- *	-	-	5.1333	2.0210	3.3538	2.5015
5	7.643	3.009	71.0	43.0	63.6	156	95	140	56.93	12.3	5.1333	2.0210	6.3536	2.5015
								Average	60.15	13.5				
Test Temperature 177°C (350°F)														
1	7.666	3.018	74.0	51.0	65.4	163	112	144	56.16	12.4	5.1346	2.0215	6.3530	2.5015
2	7.640	3.008	70.4	59.0	67.0	155	139	147	54.71	12.3	5.1333	2.0210	6.3538	2.5015
3	7.653	3.013	72.0	49.5	63.0	157	109	139	51.60	11.6	5.1346	2.0215	6.3538	2.5015
4	7.658	3.015	70.4	48.0	62.0	155	106	137	54.71	12.3	5.1333	2.0210	6.3538	2.5015
5	7.645	3.010	66.0	48.6	57.0	145	107	125	50.26	11.3	5.1346	2.0215	6.3538	2.5015
								Average	53.29	12.0				
Test Temperature 288°C (550°F)														
1	7.630	3.004	58.1	44.5	50.8	128	98	112	41.37	9.3	5.1333	2.0210	6.3538	2.5015
2	7.640	3.008	70.3	50.3	64.0	155	111	141	52.04	11.7	5.1333	2.0210	6.3538	2.5015
3	7.650	3.012	61.7	52.6	56.2	136	116	124	48.93	11.0	5.1333	2.0210	6.3538	2.5015
4	7.653	3.013	69.3	59.0	64.4	153	130	142	53.38	12.0	5.1333	2.0210	6.3538	2.5015
5	7.549	2.972	64.4	50.8	57.6	142	112	127	51.15	11.5	5.1333	2.0210	6.3538	2.5015
								Average	49.37	11.1				

Table VII. Rail Shear Strength.

Material: PMR-15/T300-182 Graphite Polyimide Composite

Specification: GE Instructions

Shear Strength: $S = \frac{P}{bd}$

P = Breakload
b = Width in cm
d = Thickness in cm

Specimen No.	Shear Strength $N/m^2 x10^7$	Shear Strength psi	Breakload Kg	Breakload lbs	Width cm	Width in.	Thickness cm	Thickness in.
Test Temperature 23° C (74° F)								
1	7.27	10,540	1255	5700	3.835	1.510	0.170	0.067
2	7.70	11,170	1275	5790	3.823	1.505	0.163	0.064
Average	7.49	10,860						

Table VIII. Rail Shear Strength.

Material: PMR-15/T300-182 Graphite Polyimide Composite

Specification: GE Instructions

Shear Strength: $S = \frac{P}{bd}$

Special Condition:
Laser Drilled Holes

P = Breakload
b = Width in cm
d = Thickness in cm

Specimen No.	Shear Strength $N/m^2 x10^6$	Shear Strength psi	Breakload Kg	Breakload lbs	Width cm	Width in.	Thickness cm	Thickness in.
Test Temperature 23° C (73° F)								
1	12.00	1740	277.0	610	3.780	1.488	0.1092	0.043
2	13.17	1910	305.8	672	3.777	1.487	0.1092	0.043
3	13.17	1910	296.2	652	3.777	1.487	0.1060	0.042
4	11.51	1670	272.1	599	3.777	1.487	0.1117	0.044
5	9.03	1310	229.0	504	3.780	1.488	0.1194	0.047
Average	11.79	1710						
Test Temperature 177° C (350° F)								
1	10.89	1580	257.1	566	3.785	1.490	0.1117	0.044
2	13.03	1890	300.1	662	3.787	1.491	0.1096	0.043
3	7.31	1060	176.7	389	3.787	1.491	0.1143	0.045
4	9.65	1400	238.0	524	3.825	1.506	0.1168	0.046
5	8.83	1280	212.6	468	3.789	1.492	0.1143	0.045
Average	9.93	1440						
Test Temperature 288° C (550° F)								
1	7.72	1120	186.3	410	3.805	1.498	0.1143	0.045
2	12.00	1740	281.7	260	3.810	1.500	0.1117	0.044
3	8.27	1200	193.6	426	3.815	1.502	0.1143	0.045
4	9.03	1310	221.7	488	3.807	1.499	0.1168	0.046
5	8.14	1180	194.4	428	3.812	1.501	0.1143	0.045
Average	9.03	1310						

Table IX. Interlaminar Shear Strength.

Material: PMR-15/T300-182 Graphite Polyimide Composite

Test Specification: ASTM D2733-70, Method A

Shear Strength: $(S) = \frac{P}{bd}$ P = Breakload in Kg

b = Width in cm d = Length in cm

Test Speed: 0.51 cm/min (20 in/min)

Specimen No.	Shear Strength $N/m^2 x10^6$	Shear Strength psi	Breakload Kg	Breakload lbs	Length cm	Length in.	Width cm	Width in.
Test Temperature 23° C (74° F)								
1	28.06	4070	954.0	2100	1.305	0.514	2.550	1.004
2	32.13	4660	1063.0	2340	1.273	0.501	2.548	1.003
3	25.37	3640	799.5	1760	1.209	0.476	2.555	1.006
4	27.44	3980	863.2	1900	1.209	0.476	2.548	1.003
5	28.61	4150	958.6	2110	1.288	0.507	2.550	1.004
Average	28.32	4108						
Test Temperature 117° C (350° F)								
1	26.20	3800	858.6	1890	1.757	0.495	2.552	1.005
2	22.68	3290	790.5	1740	1.336	0.526	2.552	1.005
3	22.48	3260	783.7	1725	1.336	0.526	2.552	1.005
4	26.75	3880	942.7	2075	1.354	0.533	2.550	1.004
5	27.72	4020	908.6	2000	1.257	0.495	2.553	1.005
Average	25.16	3650						
Test Temperature 288° C (550° F)								
1	23.44	3400		1755	1.305	0.514	2.550	1.004
2	28.06	4070		2025	1.257	0.495	2.550	1.005
3	28.75	4170		2100	1.273	0.501	2.552	1.005
4	23.72	3440		1750	1.288	0.507	2.550	1.004
5	27.58	4000		1980	1.257	0.495	2.540	1.000
Average	26.31	3816						

Table X. Coefficient of Linear Thermal Expansion.

Material:	PMR-15/T300-182 Graphite Polyimide Composite
Specification:	ASTM D696-70
Method:	Quartz Tube Dilatometer
Test Direction:	Parallel to Laminate Plies
Specimen Size:	10.8 cm x 1.27 cm x 0.32 cm (4-1/4" x 1/2" x 1/8")

CTE $\alpha = \frac{\Delta L}{L \Delta T}$

Temperature Range (T) 23° C to -54° C to 23° C (74° F to -65° to 74° F)

ΔT: 77° C (139° F)

Specimen No.	Length (L) cm	Length (L) in.	ΔL cm	ΔL in.	Coefficient of Linear Thermal Expansion cm	Coefficient of Linear Thermal Expansion in.
1	10.732	4.225	0.0020	0.0008	3.45×10^{-6}	1.36×10^{-6}
2	10.732	4.225	0.0020	0.0008	3.45×10^{-6}	1.36×10^{-6}
				Avg. α	3.45×10^{-6}	1.36×10^{-6}

Temperature Range (T) 23° C to 121° C to 23° C (74° F to 250° F to 74° F)

ΔT: 98° C (176° F)

Specimen No.	Length (L) cm	Length (L) in.	ΔL cm	ΔL in.	Coefficient of Linear Thermal Expansion cm	Coefficient of Linear Thermal Expansion in.
1	10.732	4.225	0.0023	0.0009	3.07×10^{-6}	1.2×10^{-6}
2	10.732	4.225	0.0020	0.008	2.74×10^{-6}	1.08×10^{-6}
				Avg. α	2.92×10^{-6}	1.15×10^{-6}

Temperature Range (T) 121° C to 260° C to 121° C (250° F to 500° F to 250° F)

ΔT: 139° C (250° F)

Specimen No.	Length (L) cm	Length (L) in.	ΔL cm	ΔL in.	Coefficient of Linear Thermal Expansion cm	Coefficient of Linear Thermal Expansion in.
1	10.732	4.225	0.0020	0.0008	1.92×10^{-6}	7.57×10^{-7}
2	10.732	4.225	0.0023	0.0009	2.16×10^{-6}	8.52×10^{-7}
				Avg. α	2.04×10^{-6}	8.05×10^{-7}

Table XI. Creep Rupture Test.

Material: PMR-15/T300-182 Graphite Polyimide Composite

Test Specification: ASTM E139

Test Parameters: Stress Applied to 1000-Hour Runout or Failure

Test Temperature: 23° C (74° F)

Specimen No.	Stress Load Kg x 10^3	Stress Load lb x 10^3	Hours	Elongation (%) At Loading	Elongation (%) During Test	Modulus N/m^2 x 10^{10}	Modulus psi x 10^6
1	20.41 22.68 24.95 27.22	45* 50 55 60	24* to 161 to 183 to 184	No Curve	No Curve	No Curve	
2	25.86	57	---	Specimen slipped and failed in grip area prior to load stabilization.			
3		65	---	Slipped out loading.			
Retest	25.86	57	1008	0.015	0.02	4.96	7.2
4	31.75	70	1000	0.02	0.017	7.03	10.2
5	34.02	75	**	No Curve	No Curve	7.79	11.3

*Specimen #1 Step Loaded to Failure to Characterize Load Capability

**Failed on Loading Prior to Attaining Stress Load at 27.9 Kg x 10^3 (61.5 lb x 10^3)

Table XII. Creep Rupture Test.

Material: PMR-15/T300-182 Graphite Polyimide Composite
Test Specification: ASTM E139
Test Parameters: Stress Applied to 1000-Hour Runout or Failure
Test Temperature: 175° C (350° F)

Specimen	Stress Load			Elongation (%)		Modulus	
No.	Kg x 10^3	lbs x 10^3	Hours	At Loading	During Test	$N/m^2 \times 10^{10}$	psi x 10^6
1	24.95	55	1001	0.0	0.0065	5.45	7.9
2	27.22	60	1 min.	No curve	No curve		No curve
3	26.31	58	195	0.005	0.02	6.48	9.4
4	26.31	58	---	No curve	No curve		No curve
5	26.31	58	245	0.01	0.06	6.07	8.8

Table XIII. Creep Rupture Test.

Material: PMR-15/T300-182 Graphite Polyimide Composite

Test Specification: ASTM E139

Test Parameters: Stress Applied to 1000-Hour Runout or Failure

Test Temperature: 288° C (550° F)

Specimen No.	Stress Load		Hours	Elongation (%)		Elapsed* Time in Test	Modulus	
	Kg x 10^3	lbs x 10^3		At Loading	During Test		N/m^2 x 10^{10}	psi x 10^6
1	31.75	70	3.2	0.38	No curve		7.72	11.2
2	30.84	68	42.0	0.01	0.1 0.2	5.0 Hours 20.0 Hours	7.17	10.4
3	24.95	55	57.0	0.02	0.1 0.2	1.7 Hours 24.0 Hours	7.93	11.5
4	24.49	54	54.0	0.01	0.1 0.16	17.0 Hours 54.0 Hours	4.90	7.1
5	24.04	53	53.0	0.0	0.1 0.2 0.47	8.1 Hours 30.0 Hours 181.0 Hours	9.70	14.0

*Percent of Elongation versus Elapsed Time Column Added to Show Trend of Increase when Elongation Exceeded 0.1 Percent

Table XIV. Honeycomb Sandwich Long Beam Tensile Test at 23° C.

Type Test: Honeycomb Sandwich Long Beam Test with Four Point Loading.

Purpose of Test: To Determine Actual Load-Carrying Capabilities of PMR-15/T300-182 Face Sheets in Simulated PMR-15 Inner Cowl Construction.

Properties Tested: Load Required to Fail PMR-15 Face Sheets in Tensile and Compressive Modes at 23° C (74° F), 175° C (350° F), and 288° C (550° F).

Special Conditions: Panels were Fabricated with Variations in the 10.16 cm (4 inch) Long Gage Sections to Ensure the Desired Mode of Failure. Refer to Reference Figure for Each Test and Each Test Temperature.

Test Setup: See Figure 8.

Test Specification: GE, QCSEE Design.

Tensile Test at 23° C (74° F)
(See Figure 9 for Specimen Description)

Specimen No.	Failure Load		Tensile Strength	
	Kg	lbs	MN/m^2	psi
1	891	1965	468	67,891
2	770	1698	405	58,748
3	837	1845	414	63,830
4	997	2195	524	75,932
5	810	1785	426	61,754
Average	861	1898	453	65,649

Table XV. Honeycomb Sandwich Long Beam Tensile Test at 175° C.

Type Test: Honeycomb Sandwich Long Beam Test with Four Point Loading.

Purpose of Test: To Determine Actual Load-Carrying Capabilities of PMR-15/T300-182 Face Sheets in Simulated PMR-15 Inner Cowl Construction.

Properties Tested: Load Required to Fail PMR-15 Face Sheets in Tensile and Compressive Modes at 23° C (74° F), 175° C (350° F) and 288° C (550° F).

Special Conditions: Panels were Fabricated with Variations in the 10.16 cm (4 inch) Long Gage Sections to Ensure the Desired Mode of Failure. Refer to Reference Figure for Each Test and Each Test Temperature.

Test Setup: See Figure 8.

Test Specification: GE, QCSEE Design.

Tensile Test at 175° C (350° F)
(See Figure 9 for Specimen Description)

Specimen No.	Failure Load		Tensile Strength*	
	Kg	lbs	MN/m^2	psi
1	313	690	165	23,870
2	**	**	**	**
3	299	660	157	22,828
4	440	970	231	33,556
5	326	719	171	24,865
Average	345	760	181	26,280

* Due to failure mode of test specimens, data were not used for design, but data from IITRI tests were relied upon.

** No skin failure. Entire panel disbonded.

Table XVI. Honeycomb Sandwich Long Beam Tensile Test at 288° C.

Type Test: Honeycomb Sandwich Long Beam Test with Four Point Loading

Purpose of Test: To Determine Actual Load-Carrying Capabilities of PMR-15/T300-182 Face Sheets in Simulated PMR-15 Inner Cowl Construction.

Properties Tested: Load Required to Fail PMR-15 Face Sheets in Tensile and Compressive Modes at 23° C (74° F), 175° C (350° F), and 288° C (550° F).

Special Conditions: Panels were Fabricated with Variations in the 10.16 cm (4 inch) Long Gage Sections to Ensure the Desired Mode of Failure. Refer to Reference Figure for Each Test and Each Test Temperature.

Test Setup: See Figure 8.

Tensile Test at 288° C (550° F)
(See Figure 10 for Specimen Description)

Specimen	Failure Load		Tensile Strength*	
No.	Kg	lbs	MN/m^2	psi
1	68	151	35.4	5133
2	66	146	34.2	4963
3	126	278	65.2	9450
4	61	135	31.6	4589
5	**	**	**	**
Average	80	177	41.6	6034

*Due to failure mode, data were not used for design, but data from IITRI tests were relied upon.

**Failed in loading.

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Table XVII. Honeycomb Sandwich Long Beam Compressive Test At 23° C.

Type Test: Honeycomb Sandwich Long Beam Test with Four Point Loading.

Purpose of Test: To Determine Actual Load-Carrying Capabilities of PMR-15/T300-182 Face Sheets in Simulated PMR-15 Inner Cowl Construction.

Properties Tested: Load Required to Fail PMR-15 Face Sheets in Tensile and Compressive Modes at 23° C (74° F), 175° C (350° F), and 288° C (550° F).

Special Conditions: Panels were Fabricated with Variations in the 10.16 cm (4 inch) Long Gage Sections to Ensure the Desired Mode of Failure. Refer to Reference Figure for Each Test and Each Test Temperature.

Test Setup: See Figure 8.

Test Specification: GE, QCSEE Design.

Compressive Test at 23° C (74° F)
(See Figure 11 for Specimen Description)

Specimen No.	Failure Load Kg	Failure Load lbs	Compressive Strength* MN/m^2	Compressive Strength* psi
1	304	670	160	23,196
2	330	727	174	25,159
3	315	695	166	24,051
4	343	756	180	26,166
5	312	688	164	23,812
Average	265	707	169	24,477

*Due to failure mode, data were not used for design, but IITRI data were relied upon.

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Table XVIII. Honeycomb Sandwich Long Beam Compressive Test at 175° C.

Type Test: Honeycomb Sandwich Long Beam Test with Four Point Loading.

Purpose of Test: To Determine Actual Load-Carrying Capabilities of PMR-15/T300-182 Face Sheets in Simulated PMR-15 Inner Cowl Construction.

Properties Tested: Load Required to Fail PMR-15 Face Sheets in Tensile and Compressive Modes at 23° C (74° F), 175° C (350° F), and 288° C (550° F).

Special Conditions: Panels were Fabricated with Variations in the 10.16 cm (4 inch) Long Gage Sections to Ensure the Desired Mode of Failure. Refer to Reference Figure for Each Test and Each Test Temperature.

Test Setup: See Figure 8.

Test Specifications: GE, QCSEE Design.

Compressive Test at 175° C (350° F)
(See Figure 11 for Specimen Description)

Specimen	Failure Load		Compressive Strength*	
No.	Kg	lbs	MN/m^2	psi
1	158	348	83	12,038
2	322	709	169	24,528
3	336	740	177	25,597
4	236	520	124	17,987
5	219	483	115	16,704
Average	254	560	134	19,371

*Due to failure mode, data were not used for design, but IITRI data were relied upon.

Table XIX. Honeycomb Sandwich Long Beam Compressive Test at 288° C.

Type Test: Honeycomb Sandwich Long Beam Test with Four Point Loading.

Purpose of Test: To Determine Actual Load-Carrying Capabilities of PMR-15/T300-182 Face Sheets in Simulated PMR-15 Inner Cowl Construction.

Properties Tested: Load Required to Fail PMR-15 Face Sheets in Tensile and Compressive Modes at 23° C (74° F), 175° C (350° F), and 288° C (550° F).

Special Conditions: Panels were Fabricated with Variations in the 10.16 cm (4 inch) Long Gage Sections to Ensure the Desired Mode of Failure. Refer to Reference Figure for Each Test and Each Test Temperature.

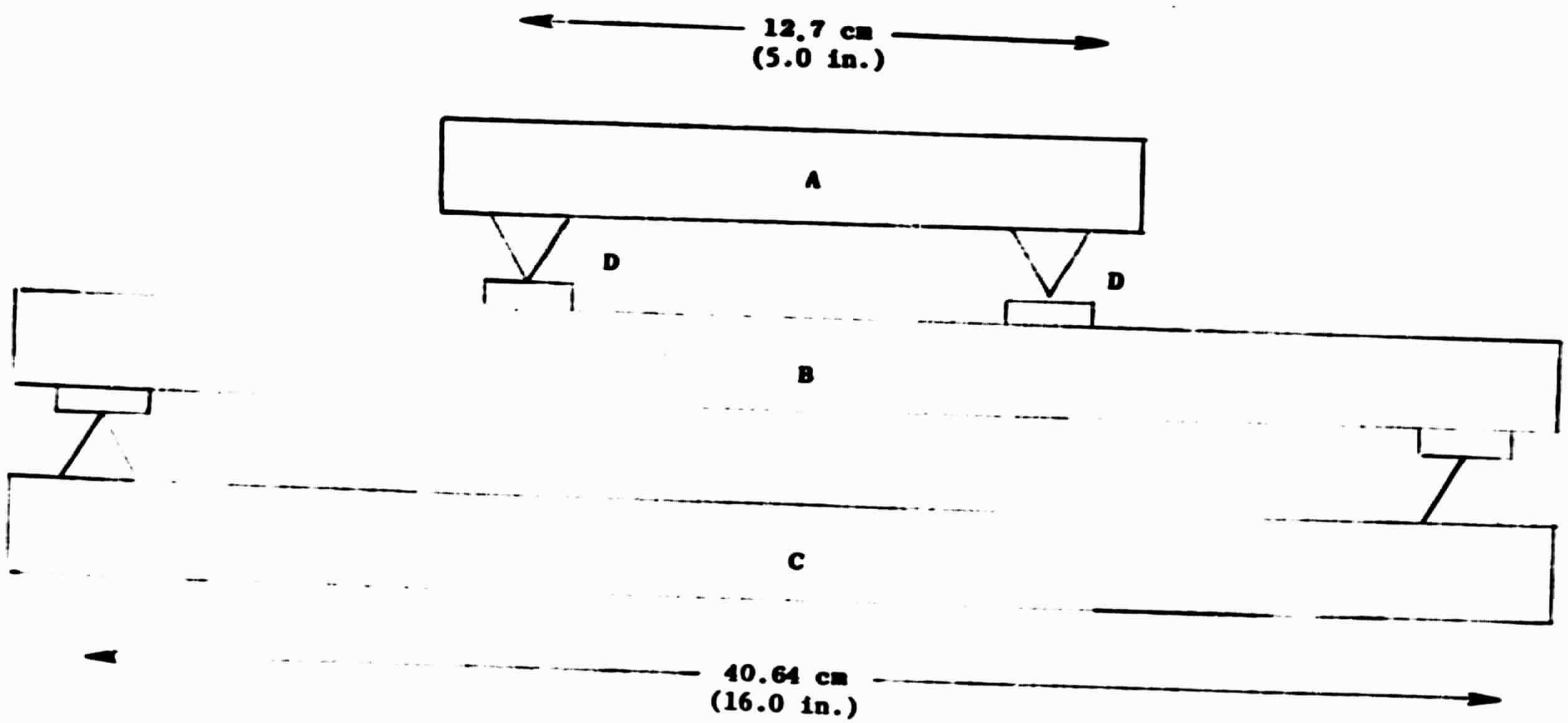
Test Setup: See Figure 8.

Compressive Test at 288° C (550° F)
(See Figure 12 for Specimen Description)

No values were recorded for this test. Thermal mismatch, due to materials selected for panel construction, resulted in premature failure due to disbond at interfaces. The maximum load applied prior to failure was 38 Kg (84 lbs).

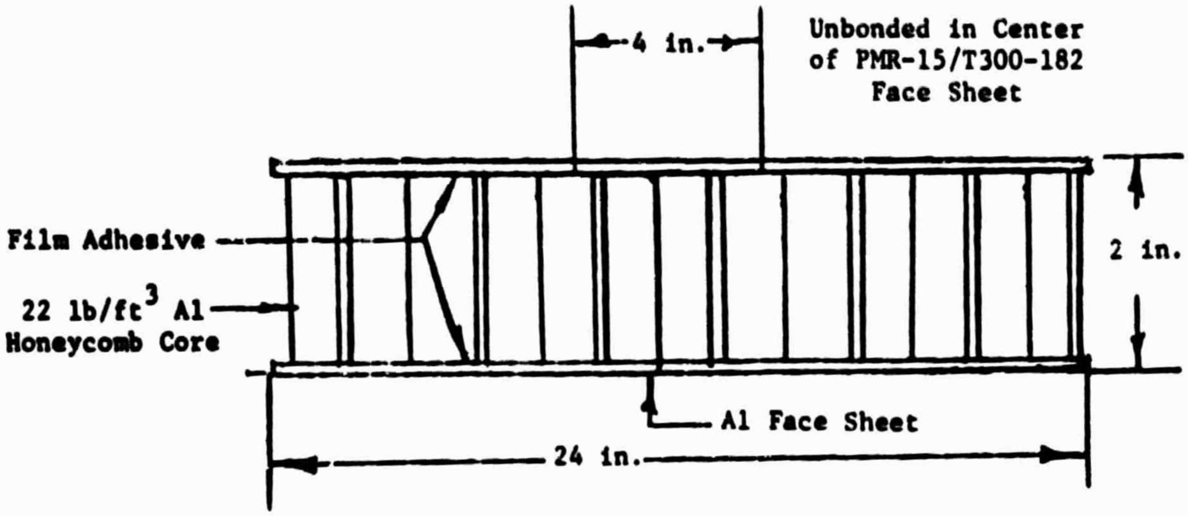
This construction is not similar to the inner cowl except for the PMR-15 skins. The panel design was intended to ensure the desired mode of failure in the skins, but the thermal mismatch caused panel failure before significant loads could be applied to the skins.

FOR TESTING LOAD CAPABILITIES OF COMPOSITE SKINS ON HONEYCOMB SANDWICH PANELS IN TENSION AND COMPRESSION MODES



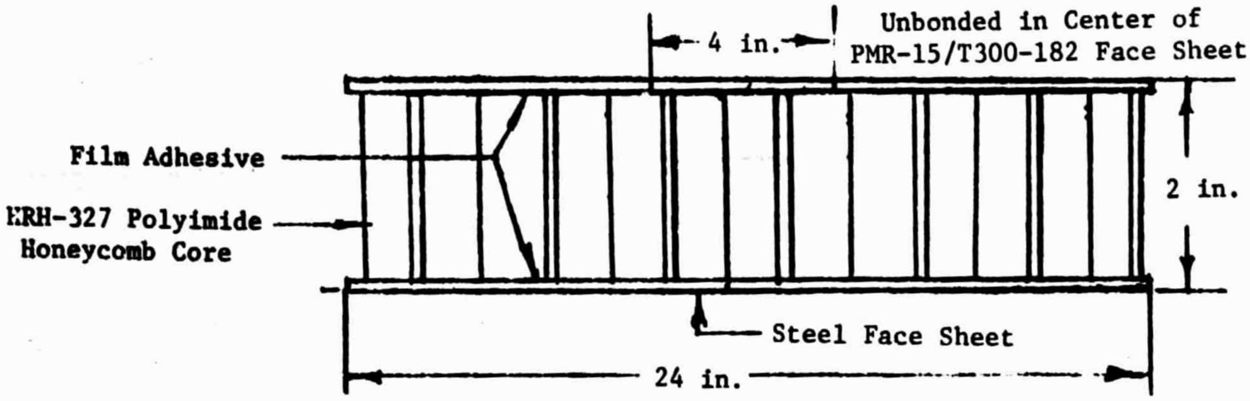
A - Upper Platen
B - Specimen
C - Lower Platen
D - Load Distribution Plates and Pivot Points

Figure 8. Beam Test with Four-Point Loading System.



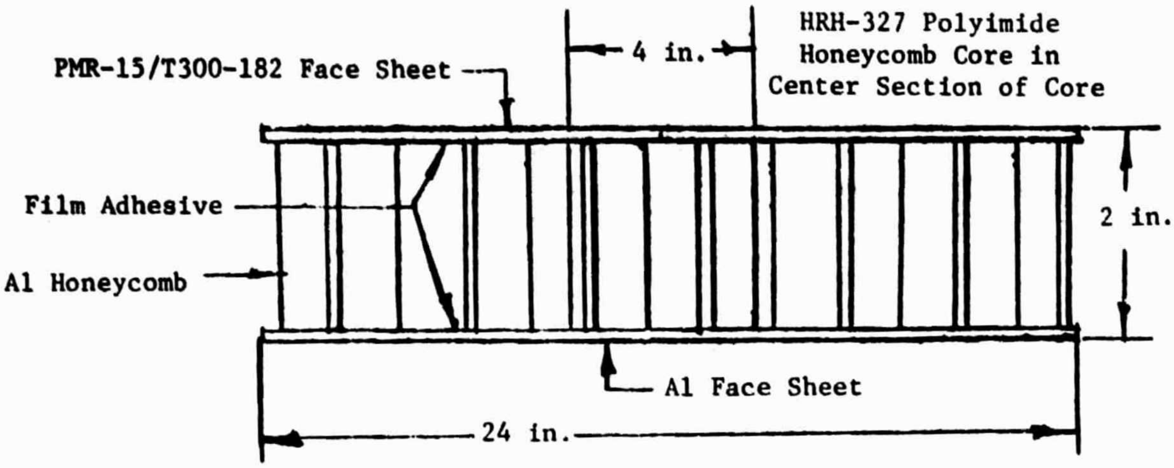
Specimen Description: 60.96 cm (24 in.) L x 5.08 cm (2 in.) H x 2.54 cm (1 in.) W, high density Al honeycomb with one Al face sheet and one PMR-15/T300-182 graphite polyimide composite face sheet. Unbonded area of 10.16 cm (4 in.) in center of PMR-15 face sheet is to ensure failure in tensile mode. (See Tables XIV and XV.)

Figure 9. Honeycomb Sandwich Beam Test Specimens Constructed to Measure Tensile Load Capability of PMR-15/T300-182 Composite Skins at Ambient and 175° C (350° F).



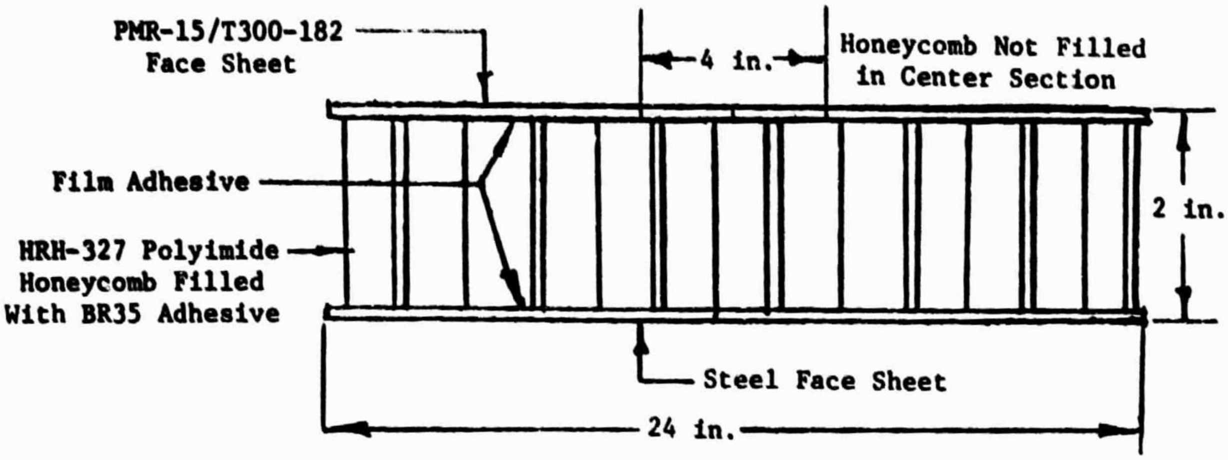
Specimen Description: 60.96 cm (24 in.) L x 5.08 cm (2 in.) H x 2.54 cm (1 in.) W, with HRH-327 polyimide honeycomb core, one steel face sheet and one PMR-15/T300-182 graphite polyimide composite face sheet. A 10.16 cm (4 in.) unbonded section in the center of the PMR-15 face sheet ensures failure in tensile mode. (See Table XVI.)

Figure 10. Honeycomb Sandwich Beam Test Specimens Constructed to Measure Tensile Load Capability of PMR-15/T300-182 Composite Skins at 288° C (550° F).



Specimen Description: 60.96 cm (24 in.) L x 5.08 cm (2 in.) H x 2.54 cm (1 in.) W, high density Al honeycomb with one Al face sheet and one PMR-15/T300-182 graphite polyimide composite face sheet. Unbonded area of 10.16 cm (4 in.) in center of PMR-15 face sheet is to ensure failure in compressive mode. (See Tables XVII and XVIII.)

Figure 11. Honeycomb Sandwich Beam Test Specimens Constructed to Measure Compressive Load Capability of PMR-15/T300-182 Composite Skins at Ambient and 175° C (350° F).



Specimen Description: 60.96 cm (24 in.) L x 5.08 cm (2 in.) H x 2.54 cm (1 in.) W HRH-327 polyimide honeycomb core filled with BR34 paste adhesive and carbon microballoons except for 10.16 cm (4 in.) unfilled honeycomb section in center section to ensure failure in compressive mode. Panels have one PMR-15/T300-182 face sheet and one steel face sheet. (See Table XIX.)

Figure 12. Honeycomb Sandwich Beam Test Specimens Constructed to Measure Compressive Load Capability of PMR-15/T300-182 Composite Skins at 288° C (550° F).

Completed panels for making test specimens were supplied to Cincinnati Testing Laboratories, Cincinnati, Ohio for machining into individual specimens and testing as specified by General Electric Company.

Description of Test Methods and Conditions

Tensile Strength and Modulus

Test Specification: ASTM D638-72
Specimen Type: IITRI
Specimen Thickness: 0.185 cm (0.073 inch) Number of plies: 5
Specimen Width: 1.27 cm (0.500 inch)
Test Temperatures: 23° C, 175° C, and 260° C (74° F, 350° F, and 500° F)
Number of Tests at each Temperature: 5 (Refer to Tables I and II)

Compressive Strength and Modulus

Test Specification: ASTM D695-69
Specimen Type: Dogbone
Specimen Thickness: 0.292 cm (0.115 inch) Number of plies: 8
Specimen Width: 1.27 cm (0.500 inch)
Test Temperatures: 23° C, 175° C, and 260° C (74° F, 350° F, and 500° F)
Number of Tests at each Temperature: 5 (Refer to Tables III and IV)

Flatwise Tensile Strength - Honeycomb Sandwich

Test Specification: ASTM C297-61
Specimen Width: 2.54 cm (1.0 inch) Plies per skin: 3
Specimen Length; 2.54 cm (1.0 inch)
Test Temperatures: 23° C, 175° C, and 288° C (74° F, 350° F, and 550° F)

Climbing Drum Peel - Honeycomb Sandwich

Test Specification: ASTM D1781-62
Specimen Width: 7.62 cm (3.0 inches) Plies per skin: 3
Test Temperatures: 23° C, 175° C, and 288° C (74° F, 350° F, and 550° F)
Number of Tests at each Temperature: 5 (Refer to Table VI)

Rail Shear

Test Temperatures: 23° C, 175° C, and 288° C (74° F, 350° F, and 550° F)
Number of Tests at each Temperature: 5 (Refer to Tables VII and VIII)
Inplane Shear

Interlaminar Shear Strength

Test Specification: ASTM D2733-70, Method A
Specimen Width: 2.54 cm (1.000 inch)
Specimen Length: 1.27 cm (0.500 inch)
Test Temperatures: 23° C, 175° C, and 260° C (74° F, 350° F, and 500° F)
Number of Tests at each Temperature: 5 (Refer to Table IX)

Coefficient of Linear Thermal Expansion

Test Specification: ASTM D696-70
Specimen Size: 10.8 x 1.27 x 0.32 cm (4.250 x 0.500 x 0.125 inch)
Temperature Span: 23° C to -37° C, 23° C to 120° C, and 120° C to 260° C (74° F to -65° F, 74° F to 250° F, and 250° F to 500° F)
Tests per Specimen: 2 (Refer to Table X)

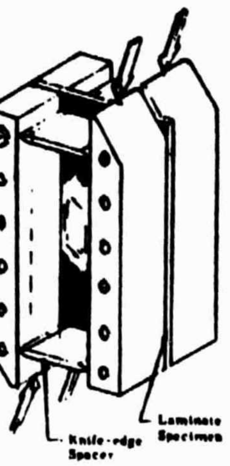
Creep Rupture

Test Specification: ASTM E139
Specimen Width: 2.54 cm (1.0 inch) Number of plies: 5
Specimen Thickness: 0.185 cm (0.073 inch)
Test Temeperatures: 23° C, 175° C, and 260° C (74° F, 350° F, and 500° F)
Number of Tests at each Temperature: 5 (Refer to Tables XI, XII, and XIII)

Shear properties in the plane of the laminate are the most difficult, controversial, and least standardized of all the major mechanical material properties. This is because pure and uniform shear stress (without secondary or normal stresses) is difficult to apply.

The rail shear test uses a thin laminate, 0.127 cm (0.050 inch) to 0.317 cm (0.125 inch) thick, 7.62 cm (3.0 inches) to 10.16 cm (4.0 inches) wide, and 15.24 cm (6.0 inches) to 20.32 cm (8.0 inches) long, loaded along its length by two pairs of rails, leaving about a 1.27 cm (0.050 inch) wide unsupported central test section. In its original concept, the rails were held apart at top and bottom by rollers. However, this device prevents transverse deflection and results in an inducted tension across the specimen under shear deflection. The use of knife edged spacers which tilt with shear distortion eliminates this problem. However, shear balancing kick loads occur at each end of the specimen and result in transverse stresses whose magnitude varies with the specimen width.

Test Specimen



Rail Shear Test Fixture

Latch Panel Test Specimen - Honeycomb Sandwich

A simulated latch installation was made in a honeycomb sandwich panel to evaluate the structural integrity of the proposed latch installation in the Inner Cowl (Table XX).

The latch installation in the inner cowl is identical to the latch installation in the outer cowl except for composite materials. The inner cowl latch test specimen was made to meet the dimensional requirements of General Electric Design Drawing 4013179-957 "Test Panel Outer Cowl - Latch" (Figure 13). The test specimens are shown in Figures 14 and 15.

Hinge Panel Test Specimen - Honeycomb Sandwich

A simulated hinge joint was made to evaluate the structural integrity of the proposed hinge installation in the inner cowl (Table XXI).

The simulated joint was manufactured to meet General Electric Design Drawing 4013179-903 "Test Panel, Hinge - Core Cowl." Materials were in accordance with the drawing requirements, and processes for honeycomb sandwich construction defined in Section 4.0 of this report were used to fabricate the test panel. See the design drawing (Figure 16) for a detailed description of the hinge test panel specimen. The test specimen is shown in Figure 17.

Curved Inner Cowl Wall - Honeycomb Sandwich

The curved inner cowl wall test specimen was designed to determine whether the PMR-15 composite skins were capable of sustaining the calculated stress loads required of the inner cowl honeycomb sandwich construction (Table XXII.

A separate design was not made for this test specimen because of its similarity to the test panels for the inlet and outer nacelle wall. General Electric Drawing 4013179-596 "Test Panel - Inlet and Outer Nacelle Wall - Curved" (Figure 18), was used as a guide to construct the panel except for a change in the radius to correspond to the smaller radius of the inner cowl. Materials were also changed to those which are specified by the Inner Cowl Design Drawing 4013057-460 "Duct, Inner-Fan Composite Nacelle QCSEE UTW."

Metal pads for four-point loading and the chord distances between pads were not changed, as shown in Figure 18.

SPECIAL TEST

Table XX. Latch Panel Test.

Test Specifications: GE, QCSEE Design

Purpose: To Determine the Stress Load Required to Fail a Simulated Latch Installation in a Panel Constructed in Accordance with the Inner Cowl Design.

Test Temperature: 23° C (74° F).

Type Failure: Tensile Mode.

Design Failure Requirement: 2608 Kg (5750 lbs) Equivalent to Three Times Maximum Stress Load.

Actual Failure Load: 2608 Kg (5750 lbs).

See Figure 13 for Design of Latch Test Panel.

Figures 14 and 15 show Simulated Latch and Latch Test Panel.

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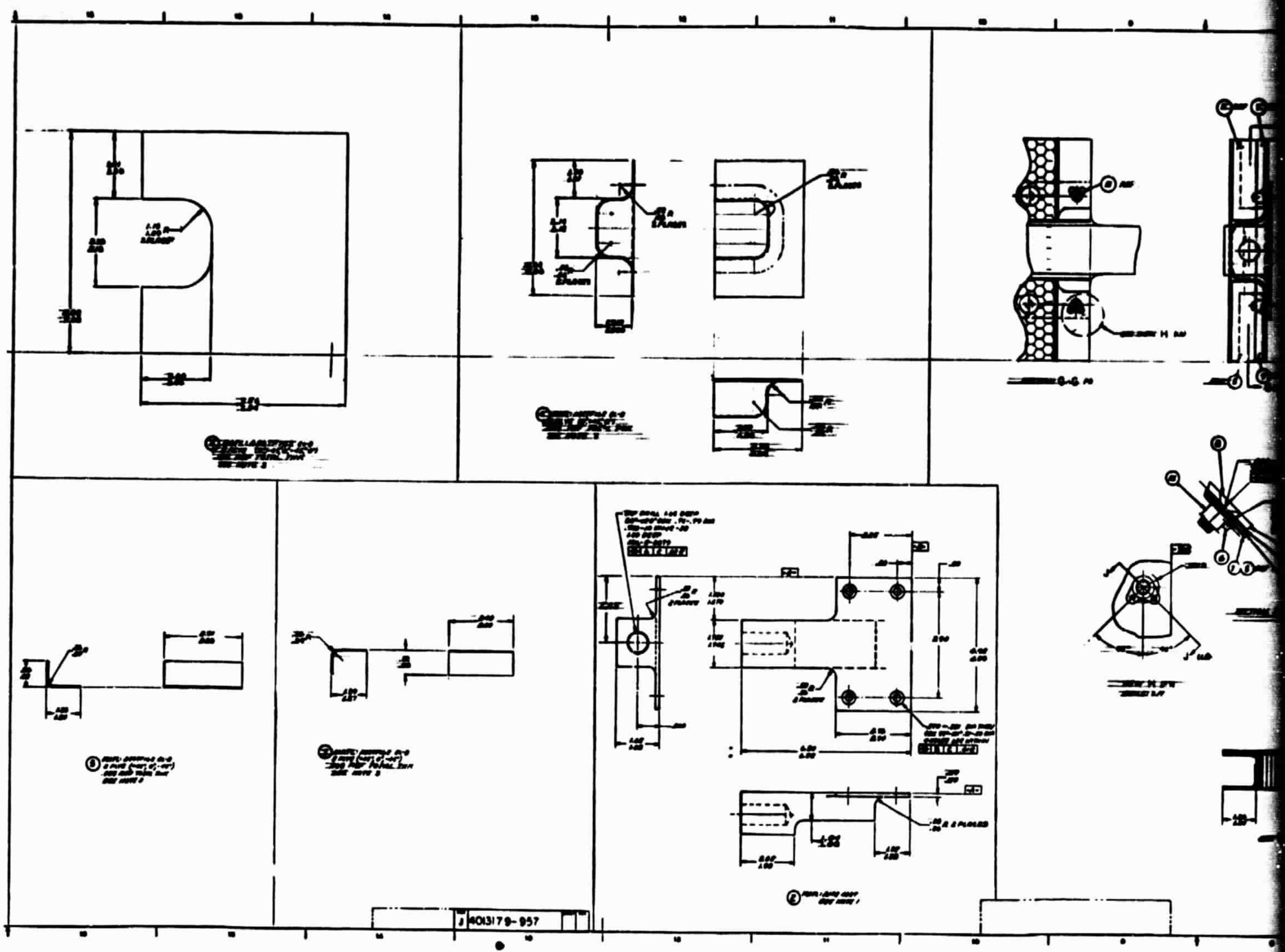

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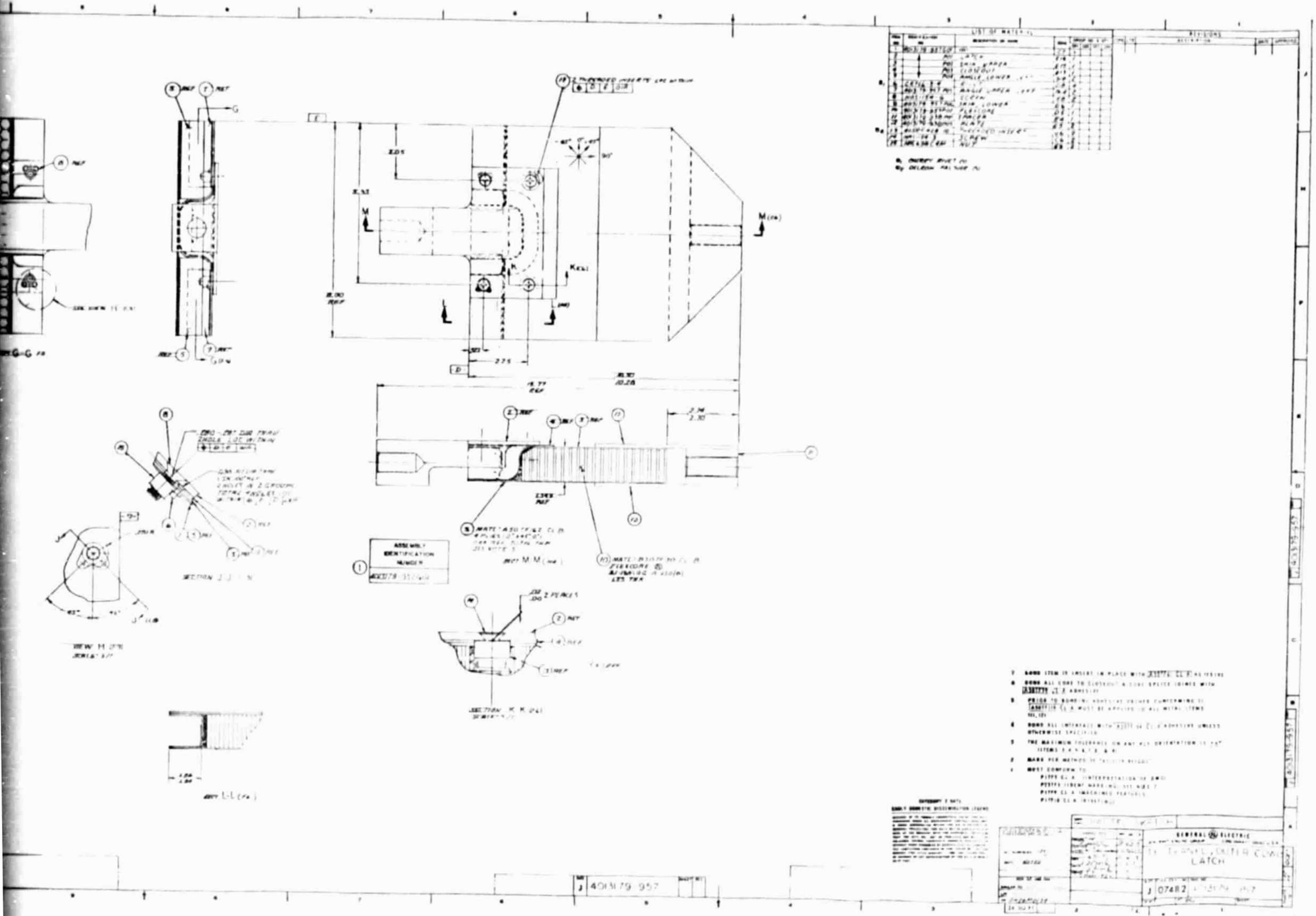

Figure 13. Test Panel, Outer Cowl - Latch.

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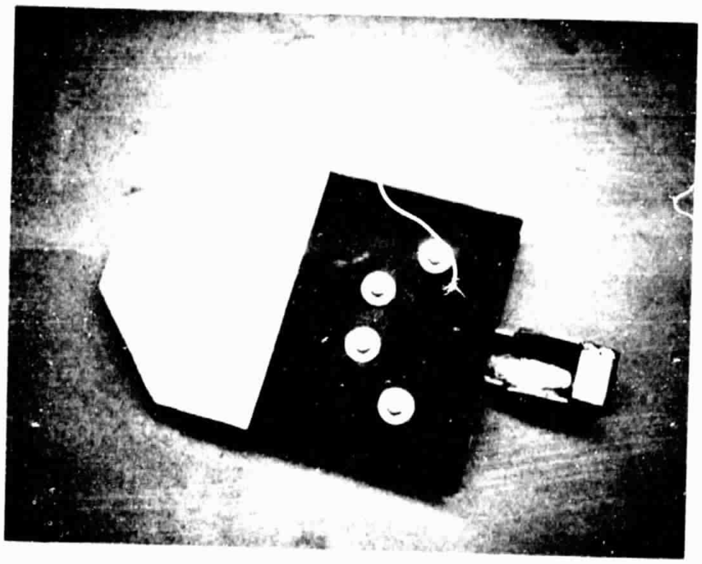

Figure 14. Test Panel with Simulated
Latch Fitting.

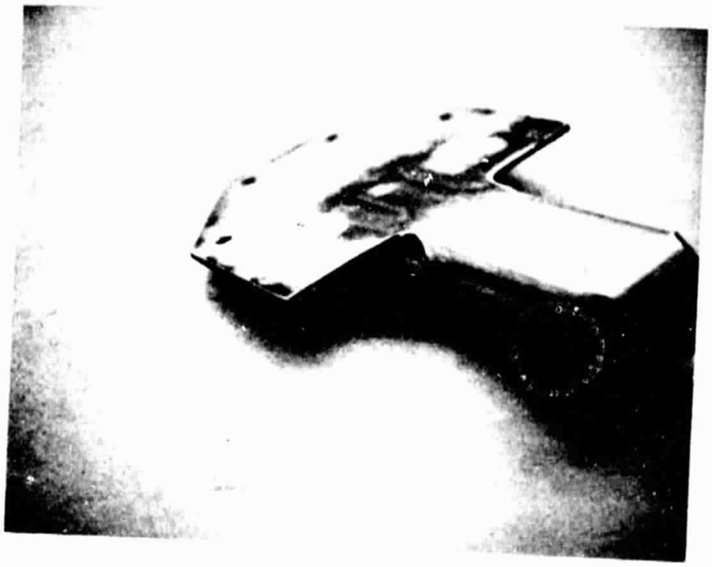

Figure 15. Simulated Latch for Latch Fitting Test Panel.

SPECIAL TEST

Table XXI. Hinge Panel Test.

Test Specification: GE, QCSEE Design.

Purpose: To determine the stress load required to fail a simulated latch installation in a panel constructed in accordance with the inner cowl design.

Test Temperature: 23° C (74° F).

Type Failure: Tensile Mode.

Design Failure Requirement: 2105 Kg (4640 lbs).
Equivalent to three times maximum stress load.

Actual Failure Load: 6985 Kg (15,400 lbs).

See Figure 16 for design of hinge test panel.

Figure 17 shows the Hinge Test Panel.

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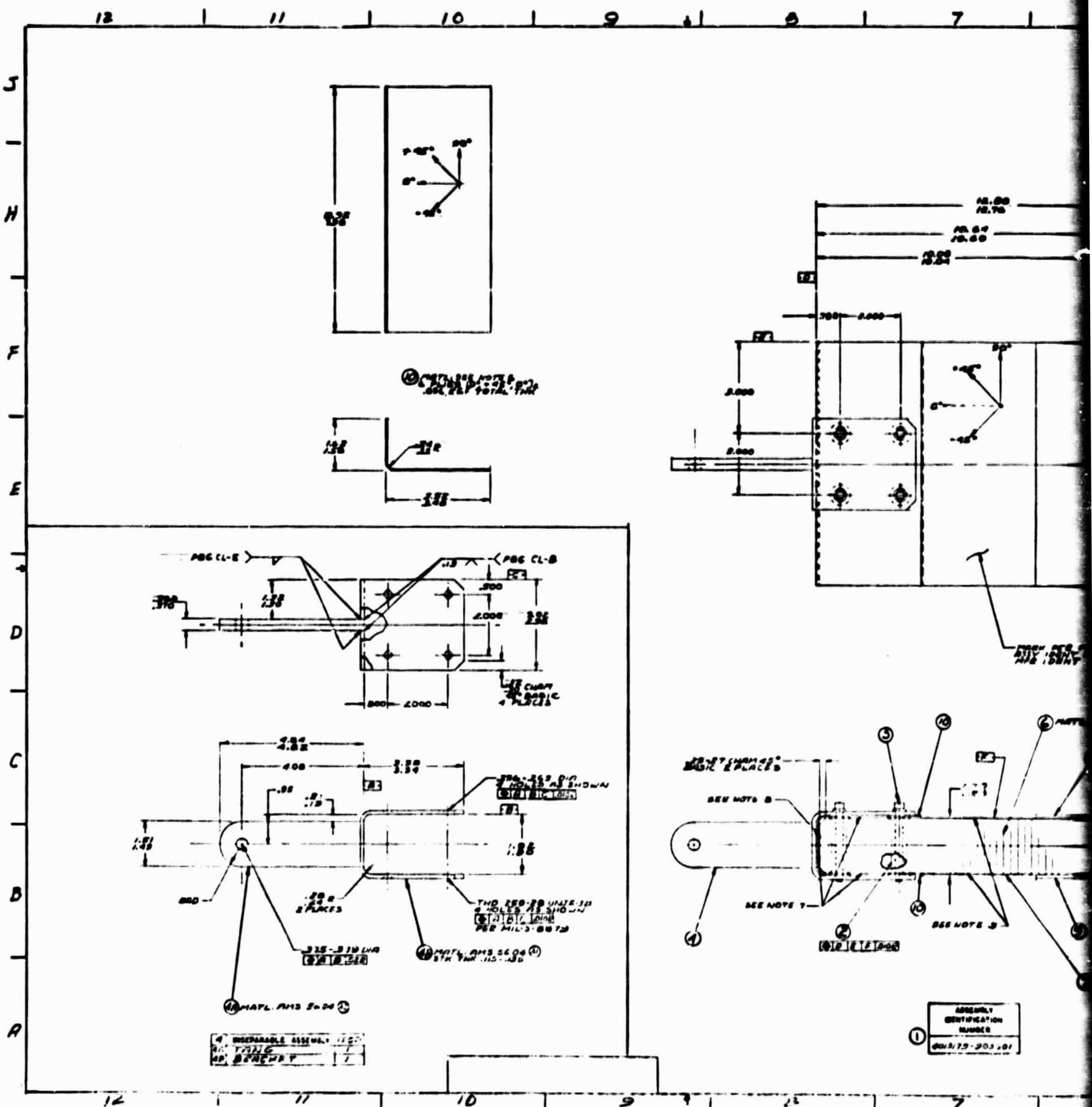

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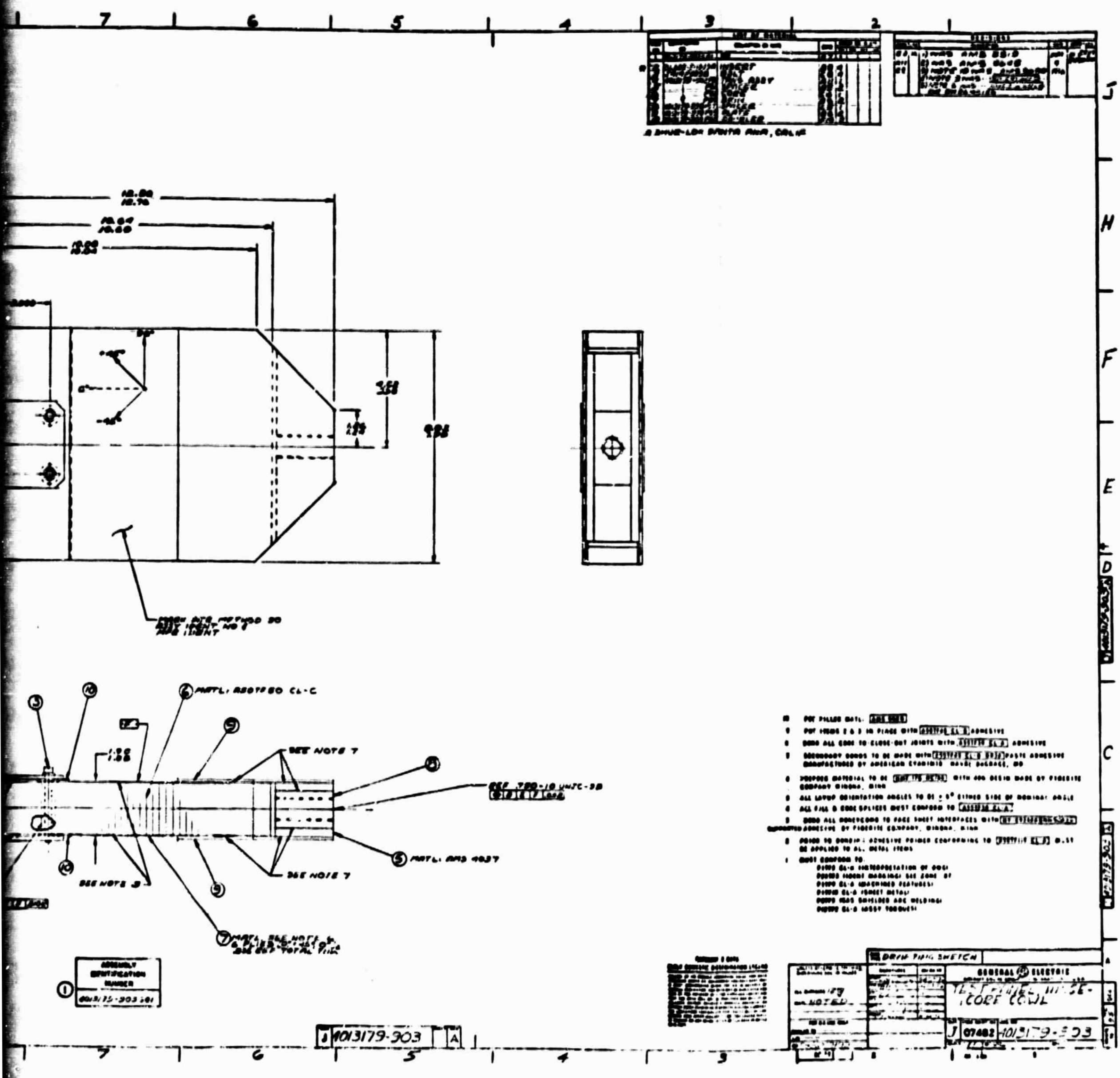

Figure 16. Test Panel, Hinge - Core Cowl.

Figure 17. Test Panel with Simulated Hinge Fitting.

SPECIAL TEST

Table XXII. Curved Inner Cowl Wall Test.

Test Specification: GE, QCSEE Design.

Purpose: To determine the stress load required to fail a simulated cylindrical section of the inner cowl wall honeycomb sandwich construction fabricated in accordance with the inner cowl design.

Test Temperature: 23° C (74° F).

Type Failure: Shear.

Method of Loading: 4 Point Beam (Refer to Figure 8).

Design Failure Requirement: 408 Kg (900 lbs).
Equivalent to three times maximum stress load.

Actual Failure Load: 402 Kg (887 lbs).

See Figure 18 for design of curved cowl wall test panel.

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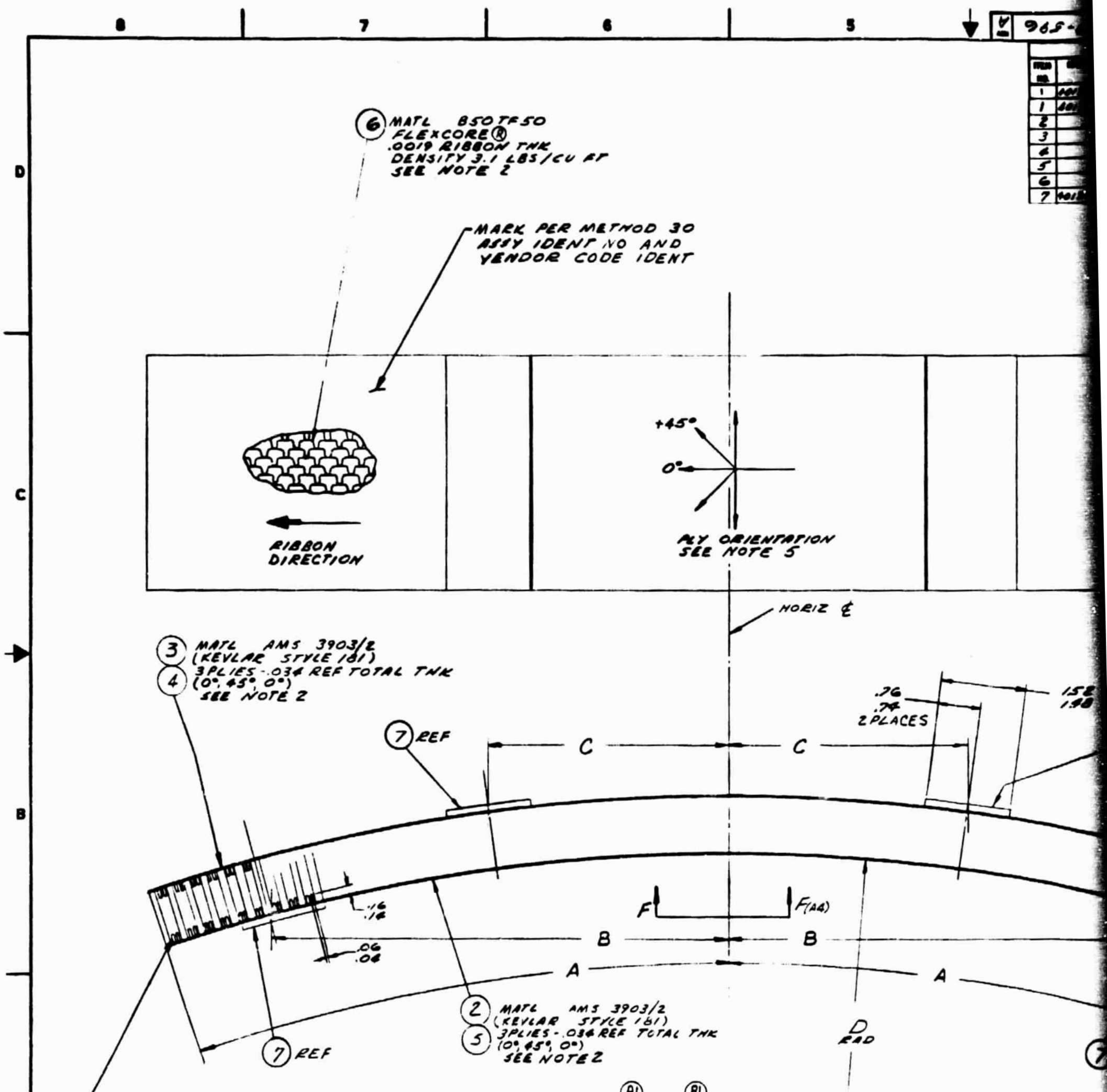

SLOT AS SHOWN ENTIRE
FLEXCORE® PANEL
SLOTS ARE TO BE LOCATED
ON BOTH SIDES OF MATERIAL
A MINIMUM OF 4 SLOTS
PER CELL MUST BE
MAINTAINED
SEE NOTE 2

1

ASSY IDENT NO	A	B (A1)	C (B1)	D	E	G	H	J	K
4013179-596601	18°-19°	8.04 8.00	4.04 4.00	31.02 30.98	1.02 .98	.16:.18	.060	36	10
4013179-596602	14°-16°	8.04 8.00	4.04 4.00	38.12 38.08	1.32 1.28				

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SEE NOTE 6

8 7 6 5 4

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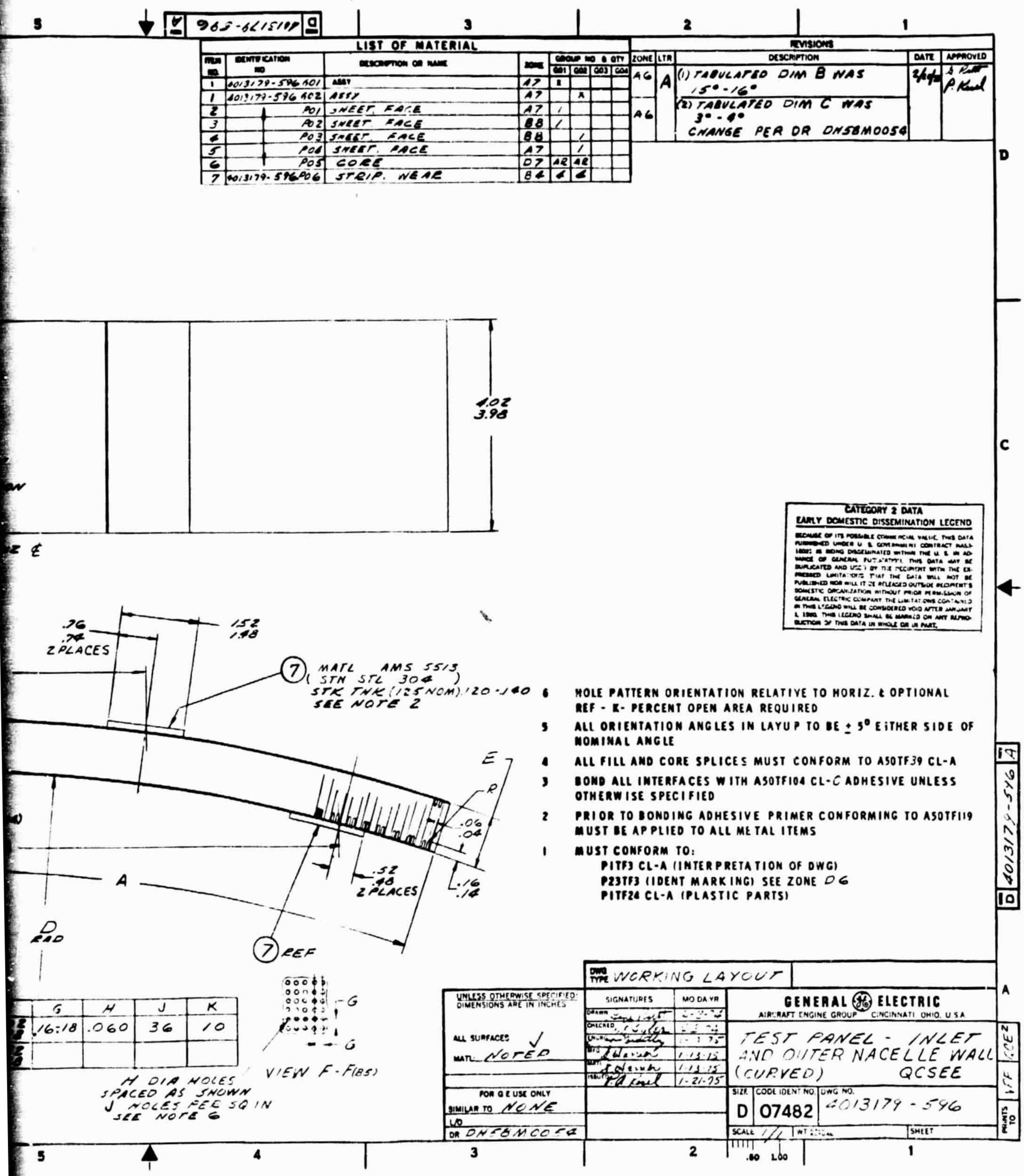

Figure 18. Test Panel - Inlet and Outer Nacelle Wall (Curved).

6.0 REFERENCES

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2. Serafini, T.T. and Vannucci, R.D., "Tailor Making High Performance Graphite Fiber Reinforced PMR Polyimides," Proceedings of the 30th Anniversary Technical and Management Conference on Reinforced Plastics - Milestone, The Society of the Plastics Industry, Inc., 1975.

3. "Industry," Technology Assessment of Graphite-Polyimide Composite Materials. NASA CR-132685, June 1975.